COMPUTER AIDED DESIGN OF RETAINING WALLS

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SYNOPSIS

An interactive graphics program for the design of earth retaining walls is presented. This considers wall stability against overturning, sliding and bearing failure.

A summary is given of methods for calculating active and passive earth pressures. From these a selection is made of methods suitable for use in the program.

The procedure for assessing wall stability is outlined with reference to the typical forces acting on a wall.

A full explanation of the interactive facilities and their use in running the program is given. The methods of data input and result output are described.

As an aid to possible program development a detailed description of the program is also presented.

Twenty-seven trial sections are analysed with the program, and the results compared with those obtained by alternative methods. A comparison is also made between simple and rigorous methods for analysing cantilever walls.

CHAPTER 1

INTRODUCTION

The modern computer is a very different machine from the early models of twenty years ago. Its speed reliability and storage capacity have increased considerably and it is now finding application in just about every field of engineering design.

The vast increase in computer usage in recent years has been accompanied by a steady increase in its application to civil engineering problems. However the effect of the computer in civil engineering design has been considerably less dramatic than in other branches of engineering. The reason for this undoubtably stems from the very creative nature of most civil engineering designs and from the difficulty of achieving a sufficiently intimate partnership between designer and machine.

In civil engineering the computer is still used primarily for lengthy routine calculations using batch processing. While certain problems are ideally suited to such a processing method, for example multi-storey frame analysis, many design problems cannot be so stereotyped as to permit efficient design using batch processing. A design will generally have an infinite number of possible solutions and while in some cases optimization techniques can be used to search for a solution, in many problems such techniques will not form a satisfactory substitute for a designer's experience and skill.

The advent of on-line methods of access to timesharing systems makes a completely new design approach possible. The engineer can now communicate with the computer. The computer is no longer an obscure calculating machine conversing with the designer by way of long lists of data and results. It has become a living assistant with which the designer can communicate directly. With the advent of interactive programming the designer has the ability to alter data and to examine instantaneously the effect on the proposed design. The design process has a continuity that was not possible under a batch system. With this approach many problems unsuitable for running under a batch system now become ideally suited to computer application.

A further development which will undoubtably find considerable application in the solution of civil engineering problems is the visual display unit. While early graphics systems proved expensive and required a considerable amount of back-up hardware advances in computer technology have led to the development of the low cost graphics terminal. Storage tube display units can now be purchased for as little as £2,000 and can be linked directly to the main computer. The facilities available with any system will of course depend on the graphics software available.

Visual display terminals will of course not prove suitable for all civil engineering problems. A rather small screen area is of little use when the output of results involves the listing of long columns of data. However for many types of design the engineer will be accustomed to working not so much from figures but from drawings and sketches. With the provision of a visual display unit this practice can be continued while at the same time the designer can take full benefit of the computers assistance in carrying out the necessary design calculations.

Retaining wall design is a problem that proves ideally suited to interactive graphics programming. The design of these structures can be considered as an essentially two part process. The primary design stage involves the selection of a wall shape which, when considered as a whole, will safely support the soil behind it without failing by sliding forward, overturning or settling excessively. Once the overall wall shape has been selected the secondary design stage involves the structural design of the various wall units e.g. for a cantilever wall the stem, heel and toe projections.

Programs already exist for both the primary and secondary design stages, however as will be seen in chapter 4, section 4.3 these are written exclusively for cantilever walls and in virtually all cases are designed for batch processing. No programs appear to have been developed using computer graphics facilities. The scope of the existing programs varies considerably with the majority of them incorporating restrictions on the nature of the ground surface behind the wall.

An interactive graphics program has been written for the primary stage of the design of retaining walls using the facilities available in the Computer Aided Design Project at Edinburgh University. One of the principal aims when developing the program was to keep the design process as flexible as possible and to avoid hindering the designer with unnecessary restrictions. The result of the work is a program that can be used for the design of both gravity and cantilever retaining walls. There are no restrictions on the shape of the ground surface behind the wall and this surface can be loaded with any arrangement of strip or line loads. Active earth pressures on the back of the wall are calculated by means of the trial wedge method while passive earth pressures are calculated by either Rankine's Method or the Friction Circle Method depending upon the shape of the front of the wall.

For cantilever retaining walls two analysis methods are available. A simple method considers earth pressures on a vertical plane through the heel of the wall, while a more rigourous method will consider the formation of an outer rupture surface between the top of the wall heel and the wall back.

An automatic design procedure is also available for cantilever walls. To use this method the designer must specify the depths of foundation required and the toe:base ratios to be considered. The program will then work through the series of sections specified and for each find the smallest base required to satisfy the design requirements. The results from such an analysis can be output in the form of either a table or a graph.

A high degree of interaction has been written into the program so that the designer can change readily from one analysis process to another, change the shape of the wall and backfill surface by graphical interaction, and make changes to soil properties as desired.

CHAPTER 2

EARTH PRESSURES AND RETAINING WALL DESIGN

2.1 INTRODUCTION

The analysis of the overall stability of a retaining wall becomes a fairly straightforward matter once the earth pressures on the wall are known.

As will be seen the lateral pressure in a mass of soil can be considered as being in one of three forms. However from the point of view of retaining wall design it is generally assumed that the earth behind the wall attains an active state of stress. The earth in front of the wall is often assumed to attain a passive state of stress although as will be discussed later this assumption may not always be justifiable (chapter 3, section 3.3.2). Given that the soil reaches the active state of stress there are several theories and equations for calculating the pressure exerted by the soil. However as will be seen the majority of these are applicable under fairly restricted conditions. For this reason they are abandoned in preference for a trial wedge method which is applicable under a far wider range of conditions.

There are several factors that may hinder the mobilization of the passive pressure in front of the wall (section 3.3.2). Because of the uncertainty that surrounds the passive pressure it is common only to include a percentage of the maximum possible pressure in stability calculations. Accordingly the same accuracy is not required when assessing the passive pressures and this can be done using one of the traditional methods.

2.2 EARTH PRESSURE STATES

2.2.1 Active Earth Pressure

If a retaining wall is moved away from the backfill thus permitting the soil behind the wall to expand laterally the pressure exerted on the wall by the soil will gradually decrease.

A point will be eventually reached at which further movement of the wall would cause shear failure of the soil mass. At this point the lateral earth pressure on the wall is a minimum and is called the active earth pressure.

Retaining walls are usually designed to withstand active earth pressures, however this is only acceptable provided sufficient wall movement has occurred to permit the development of an active state of stress in the soil mass behind the wall. The amount of lateral expansion necessary has been investigated by several researchers[10, 26], and will be discussed later (section 3.5.4).

2.2.2 Passive earth pressure

When a retaining wall moves forward permitting expansion of the soil behind the wall it will cause compression of the soil in front of the wall. As the wall moves forwards the pressure exerted by the soil on the face will steadily increase. A point will eventually be reached at which further movement of the wall will cause shear failure of the soil mass. At this point the pressure on the wall is a maximum and is known as passive earth pressure.

The lateral compression required to mobilise passive earth pressure is somewhat greater than the expansion necessary to develop an active state of stress. For this reason and because of possible interference of outside agencies on the soil in front of the wall passive pressures are often neglected from the stability analysis of retaining walls.

2.2.3 Earth pressure at rest

When no deformation of the soil mass has occurred the lateral earth pressure in a soil mass will be the earth pressure at rest. The active and passive states of stress are the two limiting cases for earth pressure. The earth pressure at rest represents a stress condition in-between these two cases.

Earth pressures at rest will be found in soil masses retained by walls which show no appreciable yield under the action of soil pressure. Basement walls are a good example of such a case.

There is no direct means of calculating the earth pressure at rest and where such conditions exist it will really be necessary to estimate the pressures involved experimentally.

However it is generally accepted that for normal retaining wall design the wall moves sufficiently to create an active state of stress in the soil behind it. No further consideration will be given to earth pressure at rest. A comprehensive summary of attempts to measure earth pressure at rest is given by Tschebotarioff[28].

2.3 METHODS OF CALCULATING ACTIVE EARTH PRESSURES

2.3.1 Introduction

No attempt will be made to prove or develop the well known theories for the calculation of earth pressure. These are widely covered in soil mechanics books.

Consideration will however be given to the conditions under which these theories are applicable because in an attempt to develop a program that will consider a wide range of problems many of the common methods of calculating earth pressures are found to be not directly applicable.

2.3.2 Rankines method

2.3.2.1 General

Rankine developed his earth pressure theories for the evaluation of the lateral earth pressure in a semi-infinite mass of soil. The lateral earth pressure on a vertical plane is assumed to act parallel to the ground surface.

When considering the earth pressure against a vertical retaining wall Rankine still assumes that the earth pressures act parallel to the ground surface(19). Rankines formula can under these conditions be considered as a special case of Coulombs formula with the angle of wall friction δ equal to the slope of the ground surface α.

2.3.2.2 Application to retaining wall design

Rankines theory is only applicable for calculation of the active pressures on a vertical plane. Consequently for the walls shown in Figures 2.1a and 2.1b Rankines method cannot

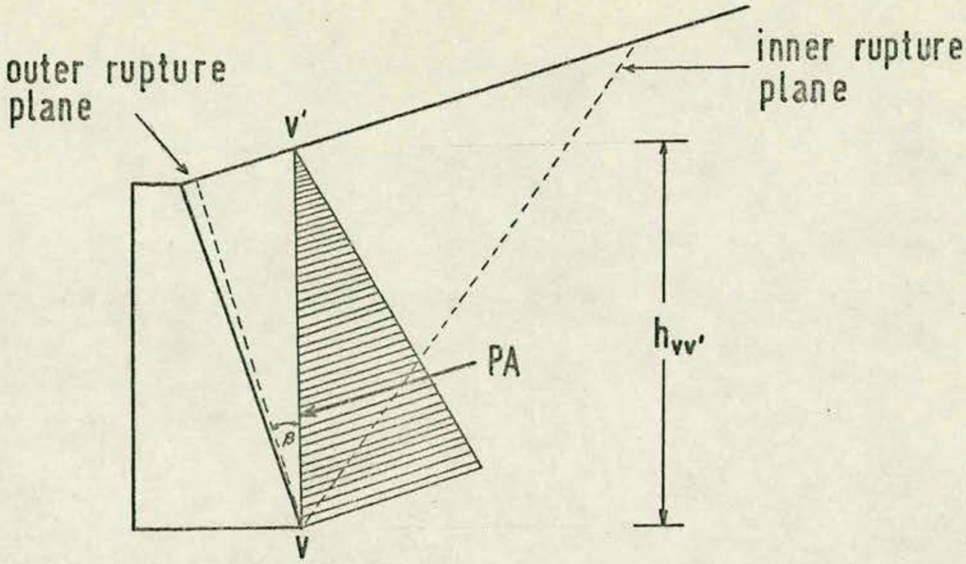


FIG. 2.1a. : RANKINES METHOD FOR GRAVITY WALLS

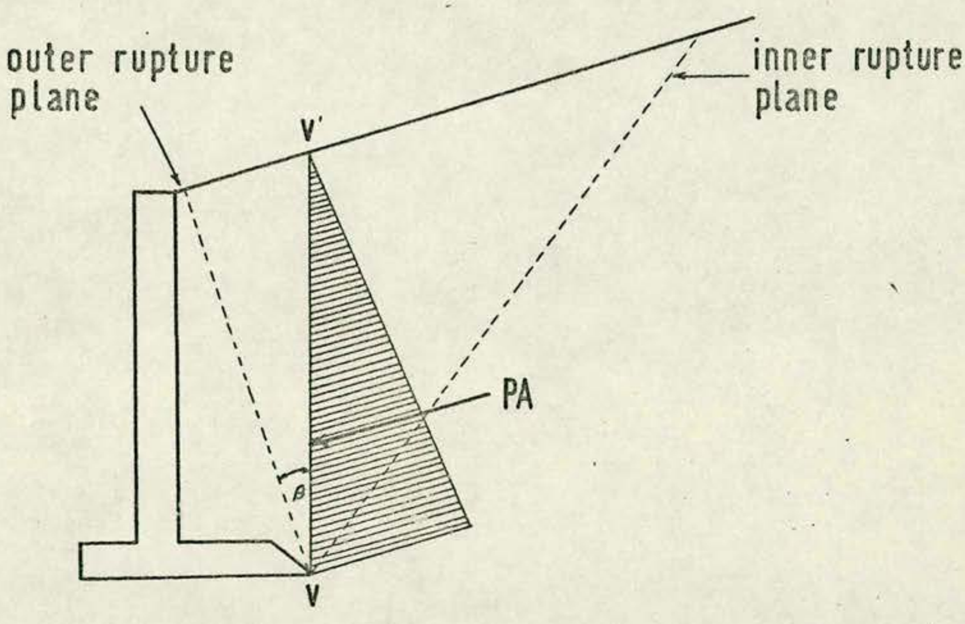


FIG. 2.1b. : RANKINE'S METHOD FOR CANTILEVER WALLS

be used to calculate the active earth pressure directly on the wall.

However provided the wall back does not interfere with the formation of the outer plane of rupture and provided the soil between this plane and the wall back moves forward with the wall and does not slide along the wall, Rankines method can be used to find the earth pressure on a vertical plane through the heel.

For the walls shown in Figures 2.1a and 2.1b the resultant active pressure on the vertical plane vv' is

$$PA = \tfrac{1}{2} \cdot \gamma \cdot h_{vv'}^{2} \cdot KA . \cos\alpha$$

$$\text{where } KA = \frac{\cos\alpha - \sqrt{\cos^2\alpha - \cos^2\phi}}{\cos\alpha + \sqrt{\cos^2\alpha - \cos^2\phi}}$$

and γ = unit weight of soil

α = angle of slope of ground surface with horizontal

ϕ = angle of internal friction of soil

The resultant force on the wall can then be found by combining the active force with the weight of soil between the vertical plane and the wall back. However if the obliquity of the resultant force is found to be greater than the angle of wall friction the initial assumption that sliding does not occur along the wall back was incorrect and Rankines method is not applicable.

The heel is shown cut away in Figure 2.1b so as to avoid interference with formation of the outer rupture plane. When the heel has not been cut away Rankines method is not strictly applicable but is often used. Huntington(9) suggests that the resulting error would only be of the order of 2%. This is of course insignificant when considered with all the uncertainties surrounding soil properties.

2.3.2.3 Conclusions

Rankines method can only be used to calculate earth pressures on retaining walls provided:-

(i) backfill surface is plane

(ii) backfill is cohesionless

(iii) there are no surface loads on backfill apart from continuous surcharge

(iv) wall back does not interfere with formation of outer rupture plane

(v) sliding does not occur between wall back and backfill material

The first three conditions severely restrict the scope of the Rankine method, and it is therefore of little use in a program which is designed to offer a high degree of versatility.

2.3.3 Coulombs method

2.3.3.1 General

Coulombs method differs from Rankines in that the soil is assumed to slide along the back of the wall. The wall is assumed to have a rough back and the active pressure on the wall will act as an obliquity δ to the normal to the wall, where δ = angle of wall friction.

Coulombs method, unlike Rankines, yields the magnitude of the active earth pressure on the wall directly. A comprehensive account of Coulombs method for calculating earth pressure on wall backs is given by Golder[7].

2.3.3.2 Application to retaining wall design

Coulombs method is strictly only applicable to walls with a plane back and where Rankines conditions are not satisfiable. However for gravity walls with small heel projections (Figure 2.2) an effective wall back AB is often assumed[4,9,25]. There will of course be some error introduced in such an approximation however this will be small provided the departure from the real surface is not large.

For this wall the resultant active pressure is given by the Coulomb equation

$$PA = \tfrac{1}{2} \cdot \gamma \cdot h^2 \cdot KA$$

$$\text{where } KA = \frac{\sin^2\{\phi + \beta\}}{\sin^2\beta \cdot \sin\{\beta - \delta\} \cdot \left\{1 + \sqrt{\dfrac{\sin\{\delta + \phi\} \cdot \sin\{\phi - \alpha\}}{\sin\{\beta - \delta\} \cdot \sin\{\alpha + \beta\}}}\right\}^2}$$

and α = angle of slope of ground surface with horizontal

β = angle of wall back with horizontal

δ = angle of wall friction

ϕ = angle of soil friction

γ = unit weight of soil

When the wall back cannot be represented by an equivalent plane surface a two part Coulomb method can be used (Figure 2.3). The pressure distribution over the two faces will be as shown in this Figure. The distribution over the top surface is triangular and the resultant pressure will act at 2/3 h1 from the top of the wall. On the lower surface the resultant pressure will pass through the centre of gravity of the trapezoidal pressure diagram.

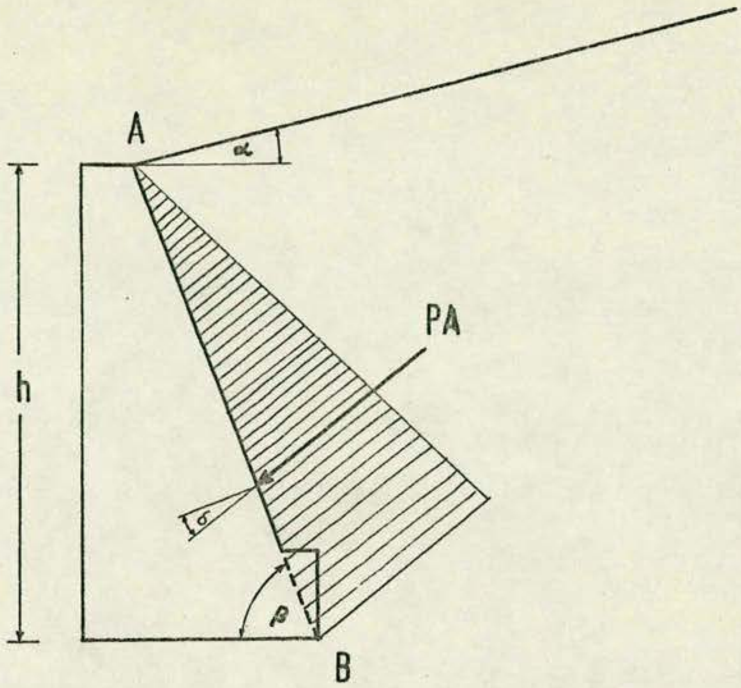


FIG 2.2. : GRAVITY WALL WITH SMALL HEEL PROJECTION

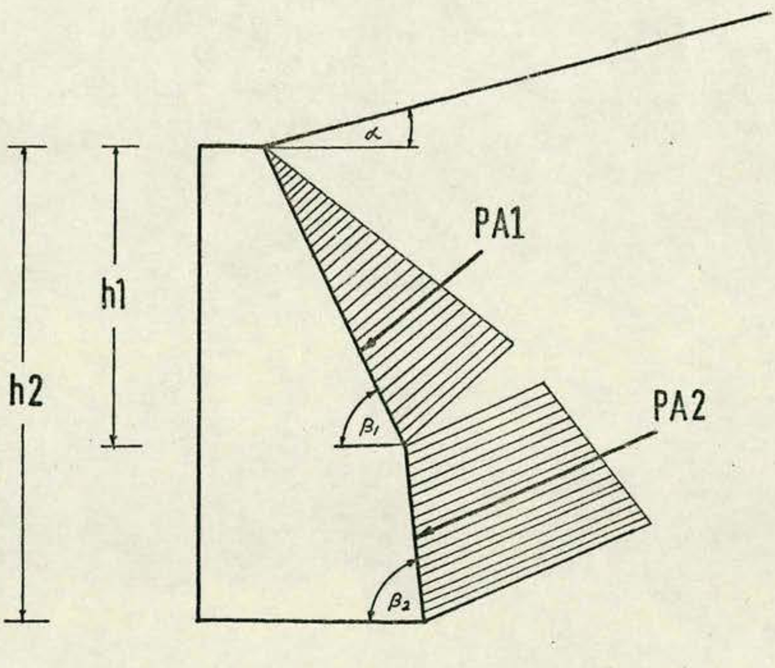


FIG 2.3. : COULOMB'S METHOD FOR WALL WITH BI-PLANAR BACK

Unlike Rankine, Coulomb also considered cohesive soil as well as cohesionless types. However because of the large number of terms involved an analytical solution is only possible for a vertical wall, horizontal ground surface and a soil which is completely cohesive ($\phi = 0$).

2.3.3.3 Conclusions

Coulomb's equations like Rankines can only be used when the backfill surface is plane. They can not be used if the backfill surface is subject to point or discontinuous surcharge loadings. Like Rankine's equations these restrictions severely limit the usefulness of Coulomb's equations.

However as will be seen Coulomb's basic theories can be used in a trial wedge analysis method (section 2.3.5) and such a method does not suffer from the limitations of Coulomb's equations but can be used when the backfill surface is non-planar and is discontinuously loaded.

2.3.4 MODIFICATIONS TO RANKINES METHOD

Bell[3] modified Rankine's theory to consider the active pressure due to cohesive backfills. However Bell's work was for the very simple case of a vertical wall back and horizontal backfill. The earth pressure was assumed to act horizontally with neither wall friction nor wall adhesion being taken into account.

Packshaw[16] extended Bell's equation to make allowance for wall adhesion and friction. Packshaw also restricted his work to vertical walls and horizontal ground. However for this condition he showed that the inclusion of wall adhesion and wall friction always resulted in an active pressure smaller than the value obtained when these terms were neglected.

Packshaw recognised that the requirements of vertical wall back and horizontal ground surface were very restrictive and recommended that when these conditions cannot be met a trial wedge method should be used.

2.3.5 TRIAL WEDGE METHOD

2.3.5.1 Introduction

As has been shown in the previous pages Rankine's and Coulomb's equations for active earth pressure can only be used under very limited conditions.

When Rankine's or Coulomb's equations cannot be applied the position of the failure plane in the soil behind the wall will not be known directly but will have to be found by examing several possible failure planes. The trial failure plane will then be the one that gives a maximum reaction on the back of the wall. This method for finding the active pressure on the wall is known as the Trial Wedge Method.

The Trial Wedge Method can be used when the backfill surface is irregular, and any form of surface loading can also be dealt with. It therefore represents the most general method available. The calculations involved in the method are very lengthy and make manual analysis an almost impossible task. However because of the repetitive nature of the calculations the trial wedge method is ideally suited to computer application.
The trial wedge method is used in the program and therefore a detailed account of its use is given in the next few sections.

2.3.5.2 Basic procedure for calculation of active pressure

Consider the wall shown in Figure 2.4a. The backfill surface behind the wall has an irregular shape and neither Coulomb's nor Rankine's equations can be used.

The active force on the wall can however be found using the trial wedge method. Various possible failure planes are considered and for each the equilibrium of the resulting failure wedge is analysed.

The triangle of forces for a typical failure wedge is shown in Figure 2.4b. The soil is assumed to slide along the back of the wall and the resultant force on the wall acts at an angle δ to the normal to the back of the wall. The resultant force on the base of the wedge acts at obliquity ϕ the normal to the wedge base. For each failure wedge the resultant force on the wall is found from the triangle of forces. If the results are plotted against the angle of the wedge base s the resulting graph will be as shown in Figure 2.4c.

The active force on the wall corresponds to the failure wedge that gives the largest lateral force on the wall and is easily read off the diagram.

2.3.5.3 Trial wedge method and Rankines conditions

When Rankine's conditions prevail the trial wedge method can be used to find the active pressure on a vertical plane passing through the heel of the wall. Figure 2.5a.
In this case however the direction of the resultant active pressure on the vertical plane is not known. The vertical plane is an arbitrarily chosen surface on which to consider the

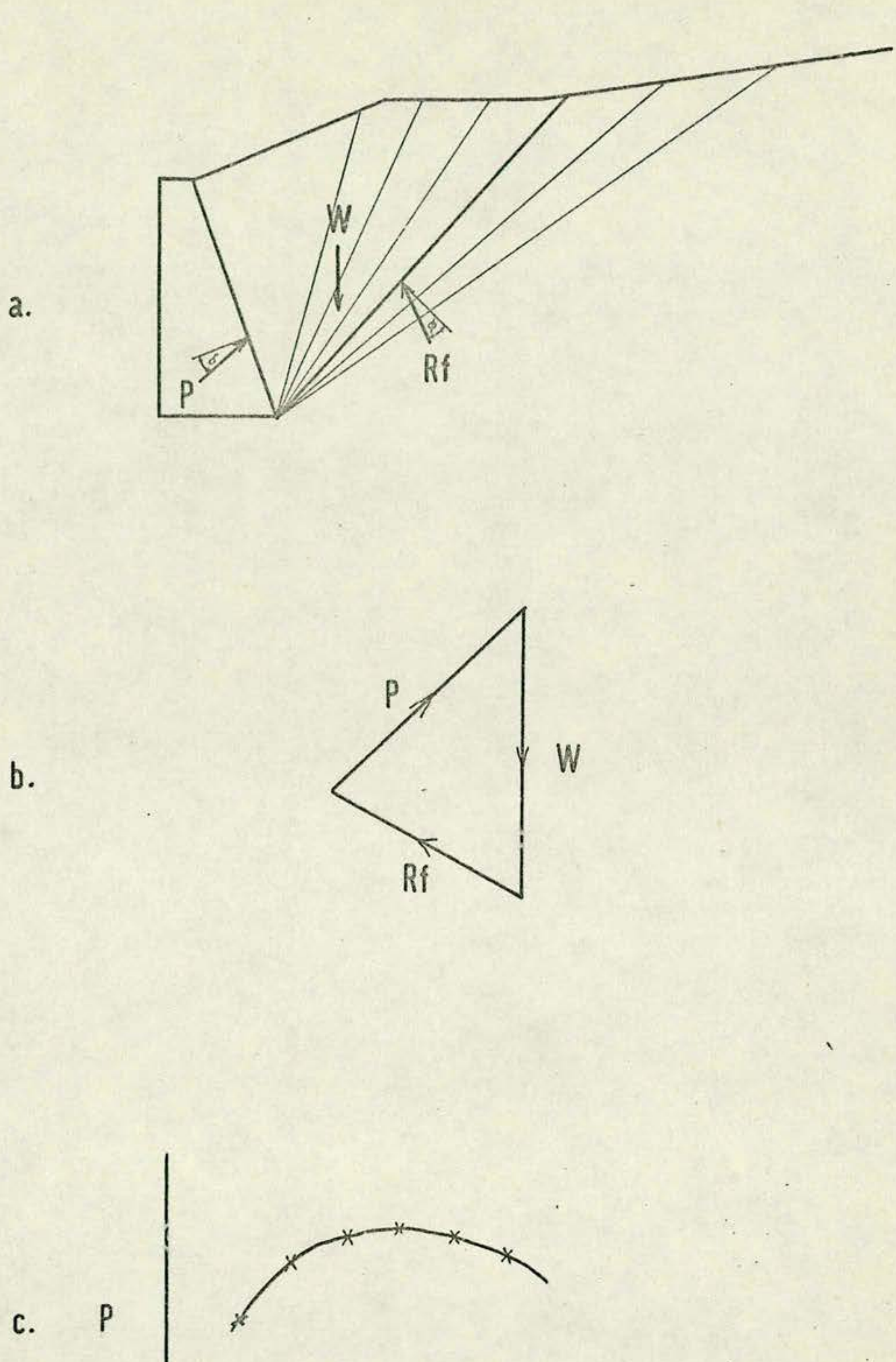


FIG 24. : TRIAL WEDGE ANALYSIS PROCEDURE

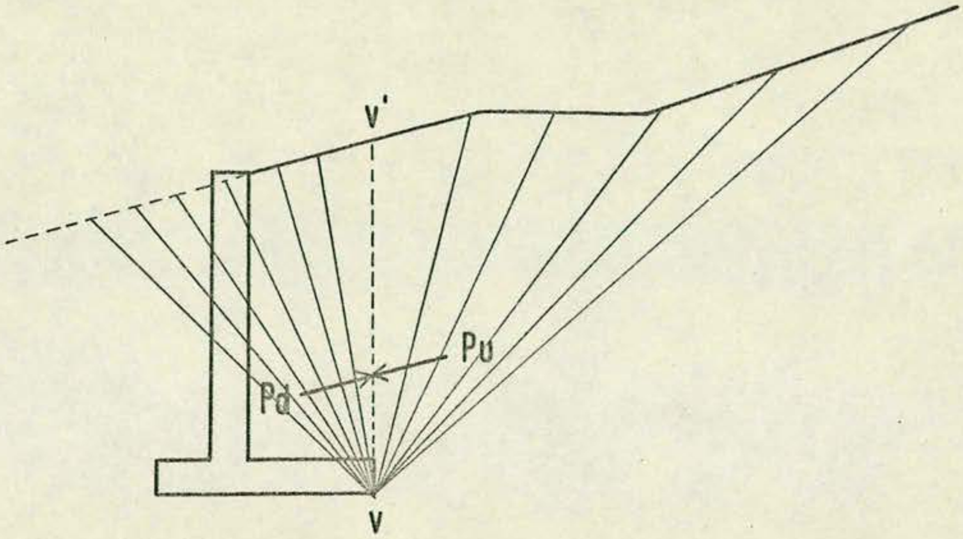


FIG 2.5.a. : HUNTINGTON'S METHOD FINDING OBLIQUITY OF ACTIVE FORCE ON VV'

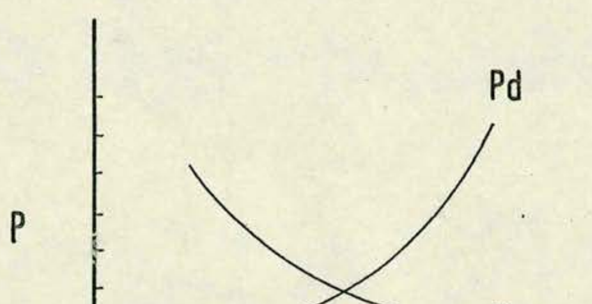


FIG. 2.5.b. : GRAPH OF UPHILL AND DOWNHILL ACTIVE FORCES ON VV' FOR DIFFERENT VALUES OF δ

earth pressures. It does not represent a failure surface and it would therefore be incorrect to assume that the resultant pressure acted at an obliquity ϕ to the normal to the surface.

When the backfill surface is plane the direction of the earth pressure will be parallel to the ground surface as in accordance with Rankine's theory. However under irregular backfill conditions there is no direct way of finding the direction of the resultant earth pressure.

Huntington(9) suggests that the direction can be found by consideration of the pressures exerted on the vertical surface by both uphill and downhill wedges. Figure 2.5a. The pressure exerted on the plane by the uphill wedge must be equal in magnitude and opposite in direction to the pressure on the plane due to the downhill wedge. The obliquity for both pressures will be the same but is unknown.

The true value for the obliquity δ is found by taking various trial values for it and calculating the resulting forces on the plane due to uphill and downhill failure wedges. The results of several trials are plotted as shown in Figure 2.5b(9). The true value of δ and the active pressure on the plane is given at the intersection of the curves.

This procedure is very lengthy and when considered against the many uncertainties and approximations that surround earth pressure calculation is unecessarily detailed.

An alternative empirical method for estimating the line of action of the active pressure is given in the AREA Manual(2). Here the active pressure is assumed to act parallel to a line drawn from the top of the wall to a point on the surface of the backfill located at a horizontal distance of twice the wall height from the back of the wall. Figure 2.6.

This method is certainly far quicker than the procedure suggested by Huntington. However it is solely dependent upon the ground surface shape and takes no account of any surface loadings on the ground. This empirical rule is therefore rather suspect.

2.3.5.4 <u>Bi-planar wall back</u>

When the wall back is not plane the Trial Wedge method can be used to find the active pressure on the various back elements. Consider for example the wall shown in Figure 2.7a.

This wall has a back made up of two plane surfaces. For such a wall the active pressure must be considered in two parts, PA1 acting on AB and PA2 acting on BC. Both forces will act at obliquity δ to the normals to the wall surfaces.

If the wall moves forward and established a state of active stress in the soil behind it any point on the back of the wall will represent the bottom of a potential surface of sliding. Point B can be taken as such a point and a trial wedge analysis carried out from it to find the active force on the top part of the wall AB.

Having found PA1 a trial wedge analysis can then be carried out from C to find the resultant active force on the lower part of the wall BC. The magnitude and direction of the force on the upper part of the wall is already known and is included in the force polygon as shown in Figure 2.7b. The object of the analysis is now to find the failure wedge that gives the maximum value for PA2.

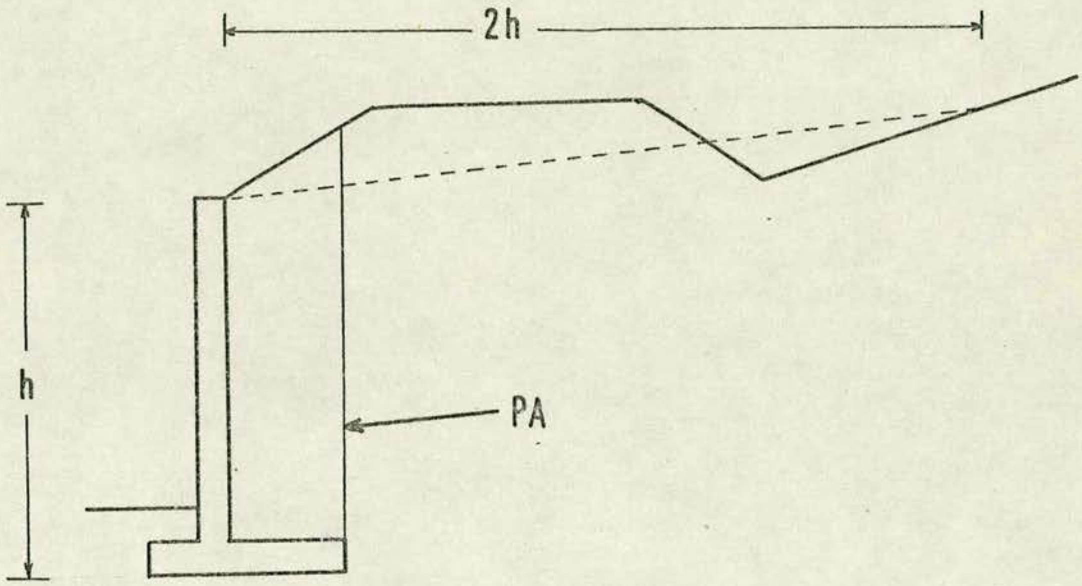


FIG. 2.6. : AREA METHOD FOR ESTIMATING LINE OF ACTION OF PA

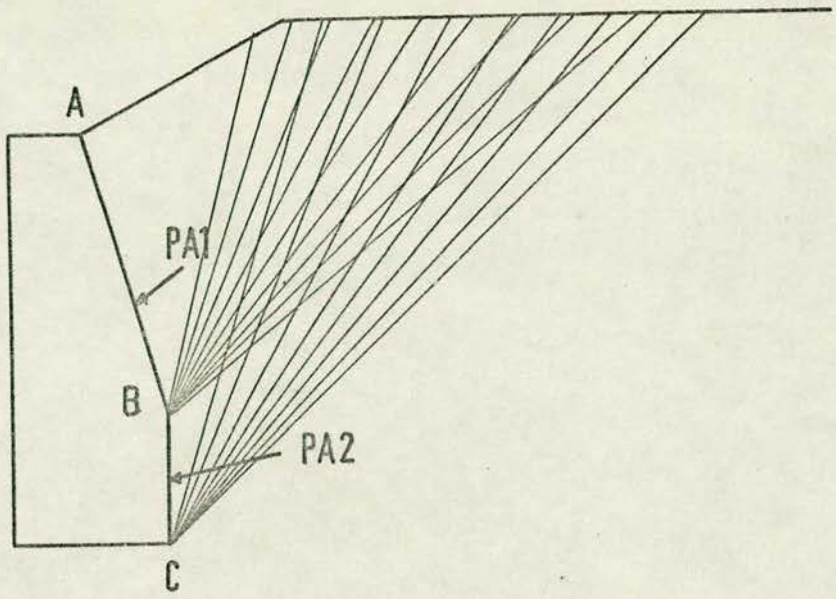


FIG. 2.7.a. : TRIAL WEDGE METHOD FOR WALL WITH BI-PLANAR BAC

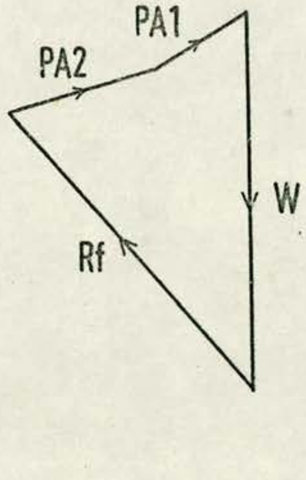


FIG. 2.7.b.: FORCE POLYGON FOR CALCULATION OF PA2

The total resultant force on the wall PA will be the resultant of forces PA1 and PA2. However as will be shown in chapter 3, section 3.1.3.2 the points of application of PA1 and PA2 can readily be found and it is then simpler to retain the forces in component form from the point of view of wall stability analysis.

2.3.5.5 Cohesive soils

The trial wedge method can be readily applied to cohesive soils although the force polygon is now slightly more complex. Two additional terms are involved. There is a cohesive force along the base of the failure wedge and an adhesive force between the wall and the backfill.

In addition to these forces consideration should be given to the effect of water filling the surface tension cracks.

2.3.6 Conclusions

In the initial plan for the program it was proposed to make provision for using both Rankine's and Coulomb's equations for the calculation of active earth pressure. The method adopted would depend upon the conditions of each particular analysis case.

When Coulomb's conditions prevail there are various ways of dealing with non-standard conditions such as a break in the backfill surface, point load on the ground surface. These methods are described both by Terzaghi [27] and Taylor[22]. However despite the amendments for certain non-standard condition these methods are strictly limited in their scope. It was therefore decided that if the program was to be kept as flexible as possible the Trial Wedge analysis method should be used for all active pressure analysis. For simpler wall and backfill shapes a trial wedge analysis may prove unnecessarily lengthy however because of the great speed of the computer in performing the analysis process there would be very little saving in time if the program reverted to an alternative analysis procedure for such cases. Furthermore it is felt that the additional amount of programming to make provision not only for alternative analysis methods but also for the checks necessary to decide upon the analysis procedure, would add considerably to the program length. The program is already lengthy without this additional burden.

2.4 METHODS FOR CALCULATING PASSIVE EARTH PRESSURE

2.4.1 Introduction

When considering the stability of a retaining wall the passive pressure developed in front of the wall will assist in preventing the wall from both overturning and sliding forward. However as discussed in chapter 3, section 3.3.2 there are several factors which may prevent the passive pressures in front of the wall from being fully developed.

Because of the possibility of these disruptive factors passive forces are sometimes excluded from stability calculations [15]. However where suitable precautions are taken to avoid or restrict disruptive agencies it would be both uneconomical and unnecessary to neglect passive pressures in the stability calculations.

The various methods for calculating passive pressures are outlined in the next few pages and particular attention is given to their usefullness for retaining wall design. From the various methods two are selected for use in the program - Rankine's Method and Friction Circle Method. These are described in some detail.

2.4.2 Rankines method

2.4.2.1 Cohesionless soil

Rankine considered the lateral earth pressure in a semi-infinite mass of cohesionless soil. When the soil was compressed sufficiently for a passive state of stress to develop Rankine showed that the lateral earth pressure on a vertical plane within the soil mass at depth h below the surface was

$$Pp = h \cdot Kp \cdot \cos\alpha .$$

$$Kp = \frac{\cos\alpha + \sqrt{\cos^2\alpha - \cos^2\phi}}{\cos - \sqrt{\cos^2\alpha - \cos^2\phi}}$$

α = angle of slope of ground surface with horizontal

ϕ = angle of soil friction

As with the active pressure case the resultant passive pressure is assumed to act parallel to the ground surface.

Rankines equation can therefore only strictly be applied to the calculation of passive pressure for retaining wall design when either both planes of rupture can develop (Figure 2.8a) or when the wall surface is vertical and the angle of wall friction is such that the resultant pressure on the wall is parallel to the ground surface (Figure 2.8b).

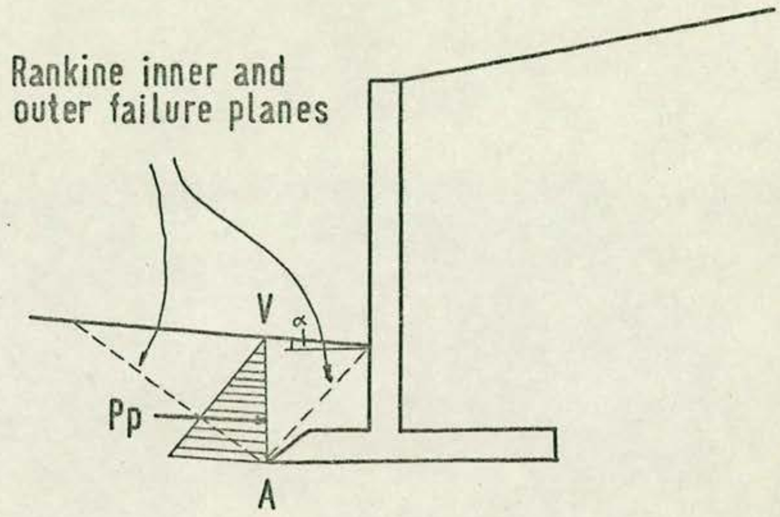


FIG. 2.8.a. : IDEAL CONDITIONS FOR RANKINES CALCULATION OF PASSIVE PRESSURE IN FRONT OF CANTILEVER WALL

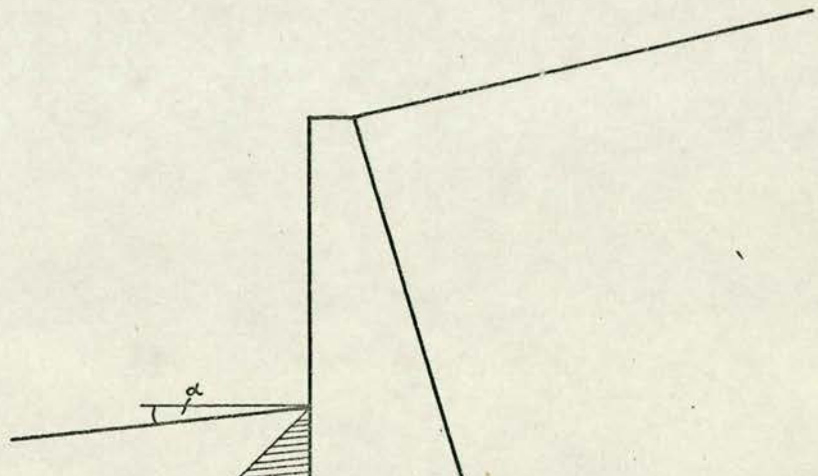


FIG. 2.8.b. : IDEAL CONDITIONS FOR RANKINE'S CALCULATION OF PASSIVE PRESSURE IN FRONT OF GRAVITY WALL

However these conditions will rarely be met in practice. The wall sections shown in Figure 2.9 are far more likely.

For such sections Rankine's equation can be used to find the passive pressure on a vertical plane through the toe of the wall. An approximation to the resultant passive pressure on the wall can then be obtained by combining the Rankine passive pressure with the weight of soil between the vertical plane and the front of the wall.

This method will of course only provide an approximate value for the passive pressure however as it is general only to utilize a percentage of the calculated passive pressure in stability calculations it should prove satisfactory.

2.4.2.2 <u>Cohesive soil</u>

Rankine did not consider cohesive soils, however his principles can be applied when the ground surface is horizontal.

For such a deposit the passive pressure at depth h is

$$Pp = \gamma . h . Kp + 2c . \sqrt{Kp}$$

$$Kp = \frac{1 + \sin\phi}{1 - \sin\phi}$$

c = soil cohesion

This passive pressure on a wall can be estimated in exactly the same manner as described in section 2.4.2.1, although as already stated the Rankine equation is only applicable to a horizontal ground surface.

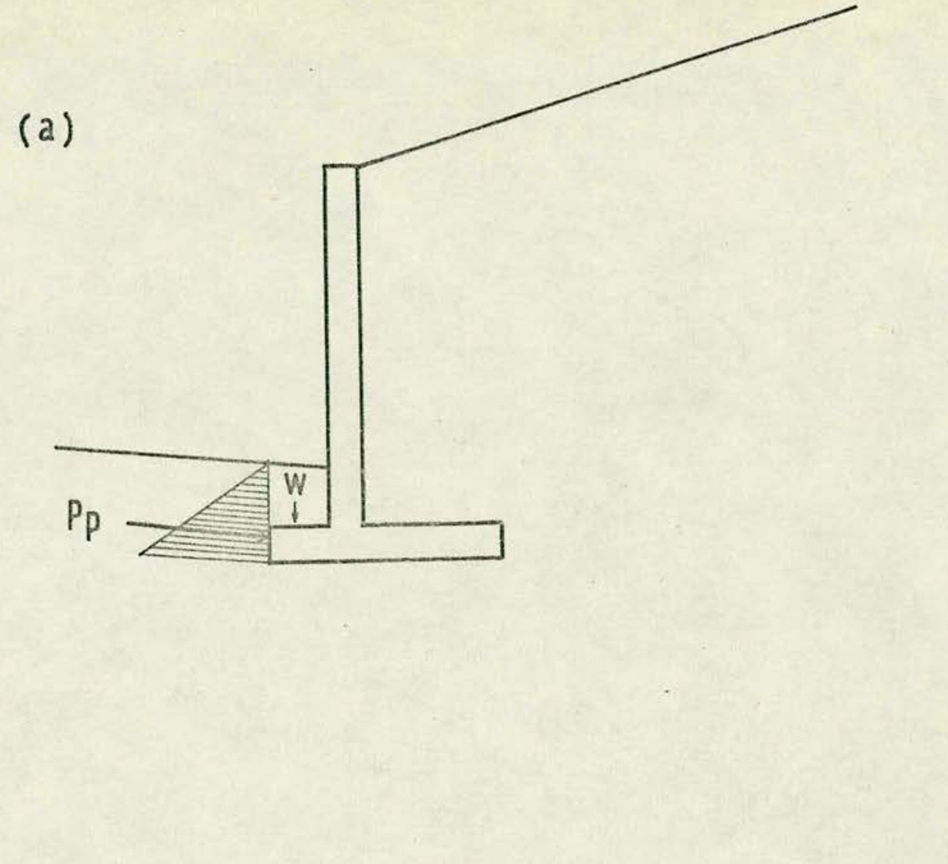


FIG. 2.9. : APPROXIMATIONS FOR RANKINES CALCULATION OF PASSIVE PRESSURE

2.4.3 Coulombs method

Coulomb did not consider passive pressure however an equation for the passive case was developed using his basic assumptions.

This method, as for the active case, assumes that the inner surface of rupture is the face of the wall. The passive pressure is assumed to have an obliquity δ to the normal to the wall where δ is the angle of wall friction. Figure 2.10

For this case a formula for passive pressure was developed :-

$$Pp = \gamma . h . Kp$$

where $$Kp = \frac{\cos(\phi + \omega)}{\cos^2\omega . \cos(\omega - \delta) . \left\{1 - \sqrt{\frac{\sin(\phi + \delta)\sin(\phi + \alpha)}{\cos(\omega - \delta)\cos(\omega - \alpha)}}\right\}}$$

and ω = angle of wall face with horizontal

α = angle of slope of ground surface with horizontal

This equation is based on the assumption of a plane failure surface. However in practice the true shape of the slip surface is curved as in Figure 2.10. The assumption of a plane surface is only justifiable for small angles of ground slope and wall surfaces that are vertical or very nearly vertical. When these conditions are not met the assumption of a plane failure surface will give considerable error, and an alternative method that takes account of the shape of the failure surface should be used e.g. Friction Circle or Logarithmic Spiral.

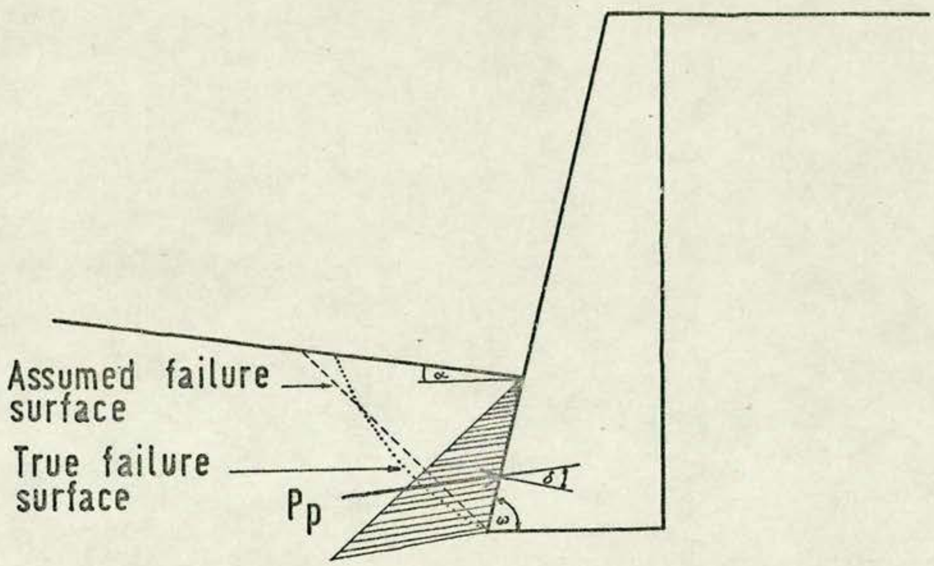


FIG. 2.10. : COULOMB'S CALCULATION OF PASSIVE EARTH PRESSURE

An equation can also be developed to cater for cohesive soils however this is only possible if the ground surface is horizontal and the wall face is vertical and can be regarded as non-adhesive and frictionless. In such a case the equation is

$$Pp = \gamma . h . Kp + 2c . \sqrt{Kp}$$

$$Kp = \frac{1 + \sin\phi}{1 - \sin\phi}$$

This is the same equation as was obtained by Bell[3] in modifying Rankine's equation to deal with cohesive soils.

However the assumption of a non-adhesive, frictionless wall face will be hard to meet in practice and this equation has therefore little practical use.

2.4.4 Trial wedge method

The principles for the calculation of passive pressures are essentially the same as for calculating the active pressure except that now it is the minimum lateral earth pressure that is sought.

This method does however suffer from the same problems as the Coulomb equation, namely the assumption of a plane surface of sliding. Complete reliability will only be assured when conditions are such that the resultant force on the wall is parallel to the ground surface i.e. the same conditions as required for using Rankine equation for passive pressure.

Departure from such conditions will result in error the magnitude of which will be determined by the degree to which the conditions are unsatisfied. These conditions severely restrict the scope of the method.

2.4.5 Friction Circle Method

2.4.5.1 General

When conditions required to use Coulomb's method cannot be met either the Friction Circle Method or the Logarithmic Spiral Method can be used to take account of the non-planar shape of the failure surface. The Friction Circle Method will be used in the program and will therefore be considered in some detail.

The Friction Circle Method assumes a failure surface that comprises two parts: a curved portion which is part of the arc of a circle and a plane portion which is tangential to the arc Figure 2.11.

The soil wedge BCD is in a Rankine state of passive stress, and the plane part of the failure surface makes an angle θ with the vertical where

$$\theta = \tfrac{1}{2} (90 + \phi) - \tfrac{1}{2} (\epsilon + \alpha)$$

and $\sin \epsilon = \dfrac{\sin \alpha}{\sin \phi}$

The surface CB defines the outer limit of the Rankine passive zone and makes an angle β with the vertical where

$$\beta = \tfrac{1}{2} \{90 + \phi\} + \tfrac{1}{2} \{ \epsilon + \alpha \}$$

For various positions of the point C on the line, a circular arc is drawn with centre lying on CC' and passing through points C and A. The plane part of the failure surface CD is drawn tangential to the curved portion.

The Friction Circle Method is then used to analyse the stability of the failure wedge and to find the resultant earth

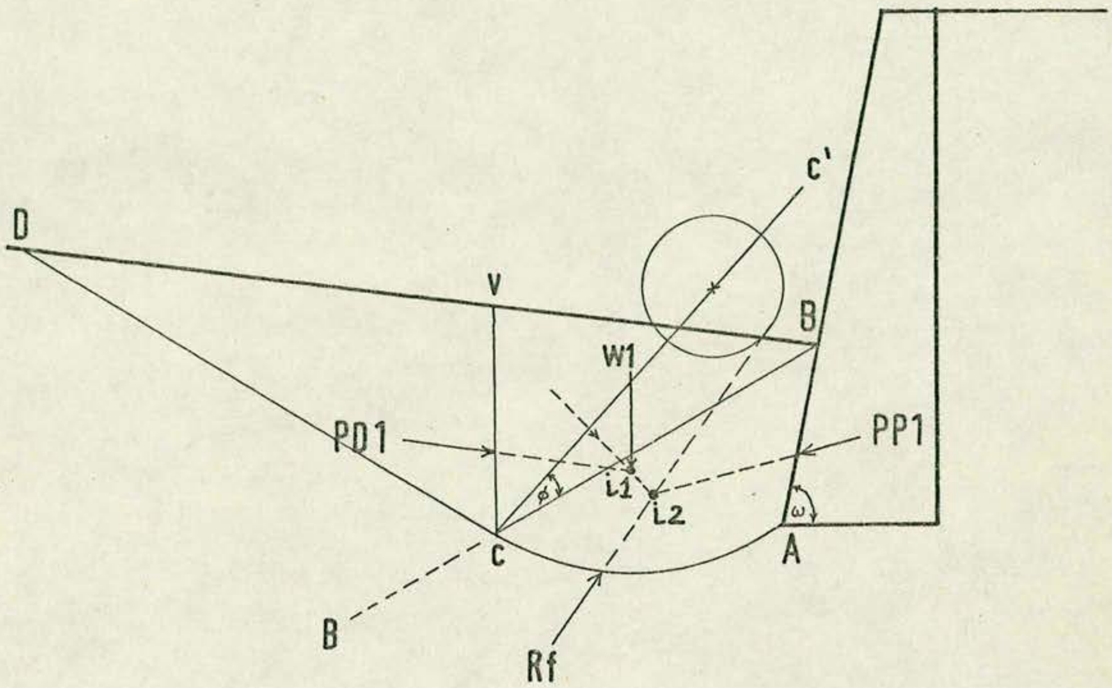


FIG. 2.11a. : FRICTION CIRCLE METHOD FOR CALCULATION OF PASSIVE FORCE

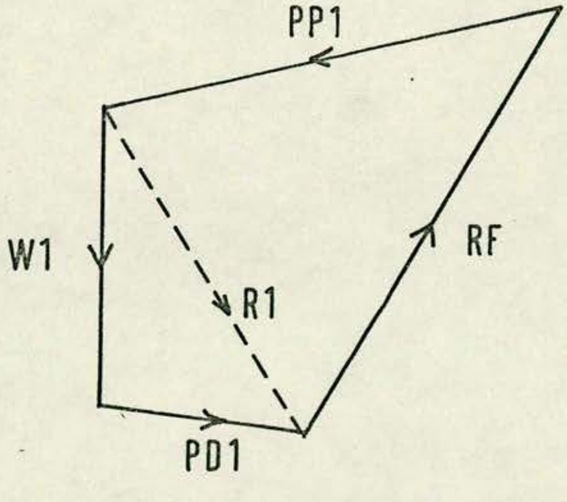


FIG. 2.11b. : POLYGON OF FORCES FOR WEDGE ABVC

pressure on the wall.

This procedure is repeated for several different positions of point C and the resultant earth pressure on the wall calculated. The smallest value of the resultant force found from such an analysis is taken as the resultant passive force on the wall.

2.4.5.2 Analysis procedure

The analysis procedure for the Friction Circle Method is described in most books on soil mechanics. However a brief outline will be given here as this may clarify the procedure adopted in subroutine FRICLE, the subroutine for calculating passive pressure by the Friction Circle Method.

(i) Cohesionless soil without surcharge:

As has already been mentioned the wedge DBC is in a Rankine passive state of stress. The resultant passive pressure on CV, PD1 can therefore be found using Rankines equation

$$PD1 = \tfrac{1}{2} \cdot \gamma \cdot hcv^2 \cdot Kp \cdot \cos\alpha$$

$$Kp = \frac{\cos\alpha + \sqrt{\cos^2\alpha - \cos^2\phi}}{\cos\alpha - \sqrt{\cos^2\alpha - \cos^2\phi}}$$

where α = angle of inclination of ground surface with horizontal

ϕ = angle of friction of soil

h_{cv} = vertical height CV

The equilibrium of the 'wedge' ABVC can now be considered. The forces acting on this wedge are shown in Figure 2.11a. Of these the unknowns are the magnitude of P_{P1} and the magnitude

line of action and point of application of R_F .
However the direction and point of action of R_F can be found because the friction circle technique is based on the assumption that the resultant force on the circular part of the failure surface is tangential to a circle, with the same centre as the circular slip surface, and with a radius of $R1.\sin\phi$, where R1 is the radius of the slip surface.

Given this fact and the fact that for wedge equilibrium R_F must pass through the intersection point $i2$ on Figure 2.11a the direction, and point of application of R_F can be found.

The polygon of forces can now be drawn Figure 2.11b. The directions of PD1 is parallel to the ground surface. The soil is assumed to slide up along the face of the wall and PP1 therefore acts at obliquity δ to the normal to this surface. From the diagram the magnitude of PP1 can readily be obtained. The distribution of passive pressure over the wall will increase linearly with depth and the resultant passive pressure will act one third of the way up the wall.

It is worth noting here that the friction circle technique is not exact. Taylor[23] has shown that the resultant on the wedge base is tangential to a circle with a radius slightly greater than RC. However the assumption of a radius of RC means that the angle that R_F is assumed to make with the horizontal is in fact larger than the true value. This means that the value calculated for P_P is in fact smaller than the true value. However since passive pressures assist wall stability any error is on the safe side.

(ii) Cohesionless soil with surcharge:

When there is a uniformly distributed surcharge on the ground surface it is necessary to carry out a two part analysis process.

Initially the presence of the surcharge is ignored and the force on the wall due to the soil PP1 calculated as in (i) (Figures 2.12a and 2.12b). This force acts at obliquity δ to the normal to the wall and at $^1/_3$ h from the base of the wall.

The calculation of the passive pressure is completed by ignoring the unit weight of the soil and calculating the passive pressure that can be mobilized due to the surcharge (Figures 2.13a and 2.13b).

The passive pressure due to the surcharge is distributed uniformly over the face of the wall and the resultant pressure PP2 acts half way up the wall.

(iii) Cohesive soil and surcharge:

Again a two part analysis procedure is necessary. Initially the unit weight of the soil is assumed to be zero and the passive pressure that can be developed as a result of soil cohesion and surcharge loading is calculated (Figure 2.14a).

The resultant passive pressure on CV can only be found by Rankine's equation if the ground surface in front of the wall is horizontal. In such a case

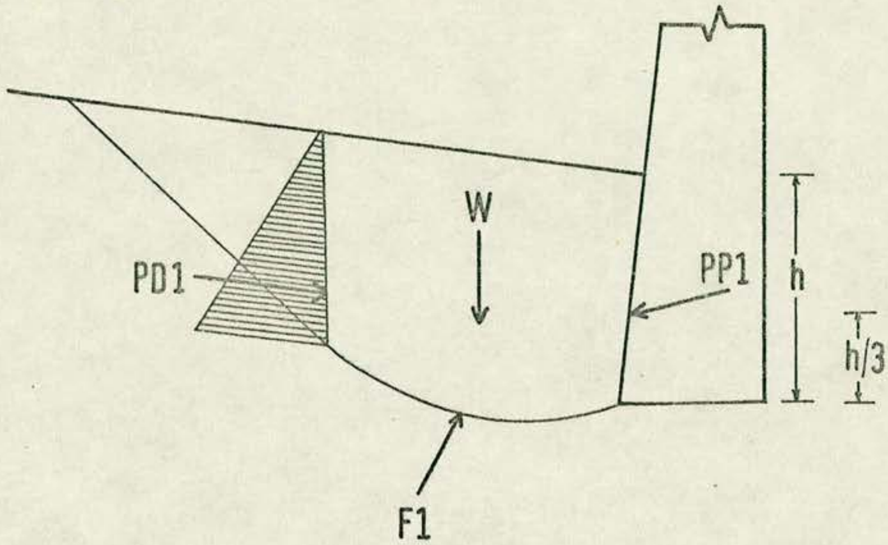


FIG. 2.12.a. : CALCULATION OF PASSIVE PRESSURE IGNORING SURCHARGE

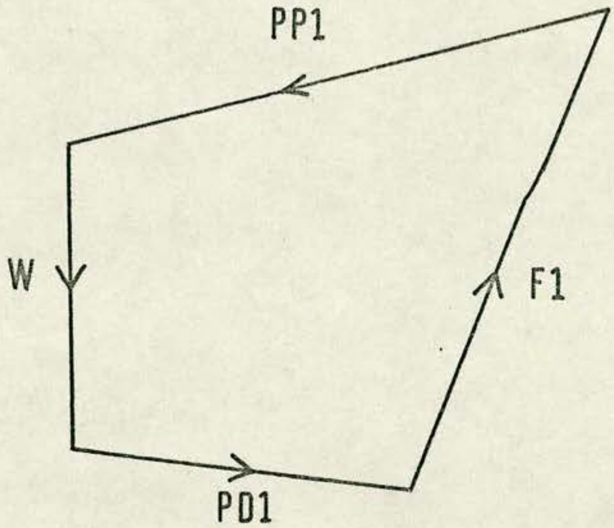


FIG. 2.12.b. : POLYGON OF FORCES FOR CALCULATION OF PP1

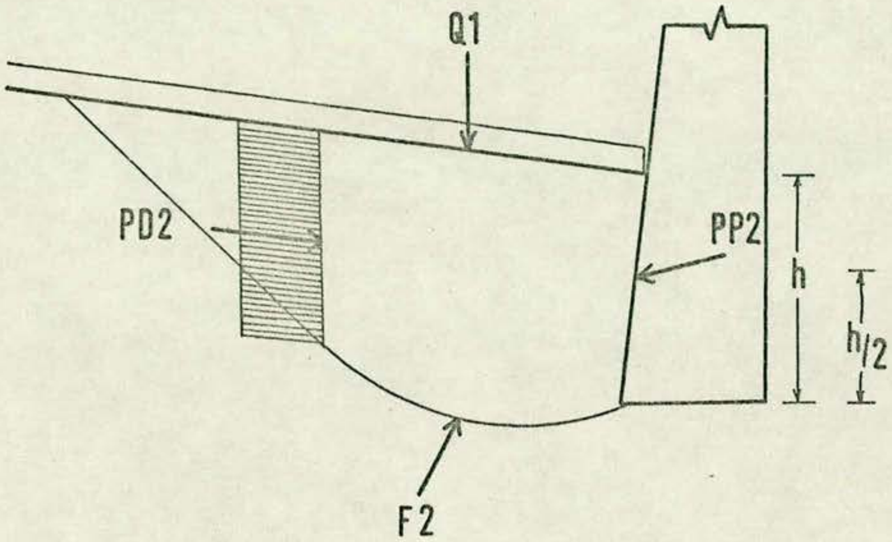


FIG. 2.13 a. : CALCULATION OF PASSIVE PRESSURE DUE TO SURCHARGE

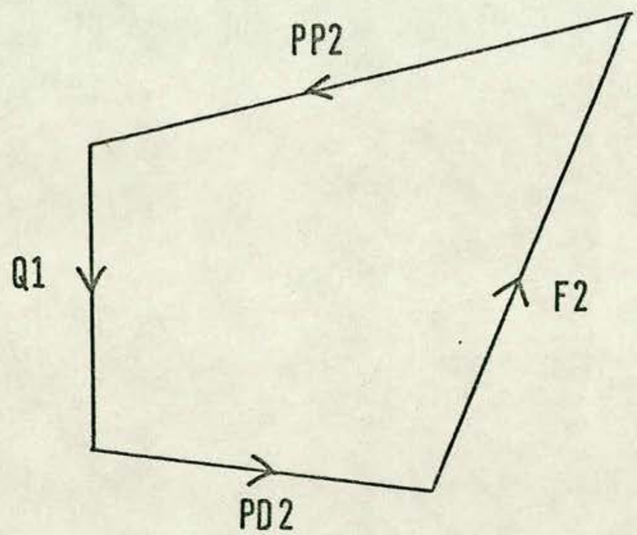


FIG. 2.13 b. : POLYGON OF FORCES FOR CALCULATION OF PP2

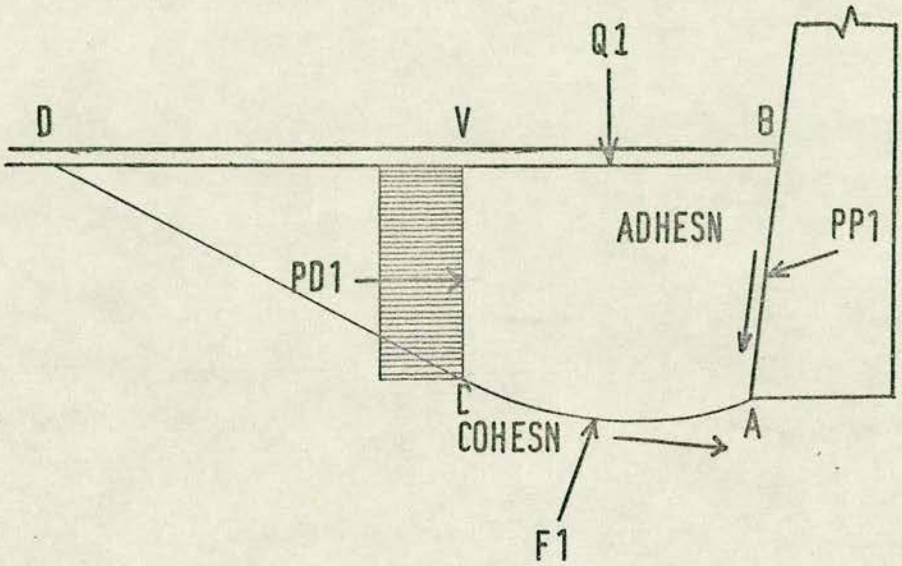


FIG. 2.14a.: CALCULATION OF PASSIVE PRESSURE DUE TO SOIL COHESION AND SURCHARGE

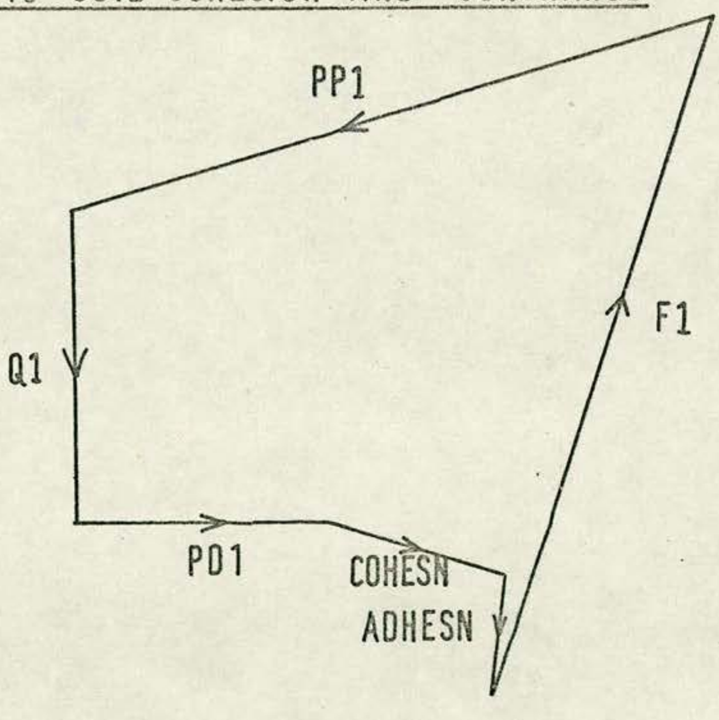


FIG. 2.14b.: POLYGON OF FORCES FOR CALCULATION OF PP1

$$PD1 = q.\ Kp.\ h_{AV} + 2c.\ h_{AV}.\ \sqrt{Kp}$$

$$Kp = \frac{1 + \sin\phi}{1 - \sin\phi}$$

The magnitude of the cohesive force acting along the curved part of the failure surface CA is simply cohesion x arc length. However to permit this force to be considered in the polygon of forces it will have to be replaced by an equivalent resultant.

If the arc AC is considered as a series of elements of length δs the cohesive force along any element is $c \times \delta s$. This force can be resolved into components parallel and normal to the chord AC. The sum of these components parallel to AC is cohesion x chord AC while the sum of components normal to AC is zero. The point of application of the resultant force can be found by taking moments about the circle centre. The distance of the cohesive resultant from the circle centre will then be given by l, where

l = Rl * arc AC/chord AC

The adhesive force on the face of the wall is given simply by the wall length times the soil-wall adhesion.

The resultant passive pressure on the wall PP1 can be found from the polygon of forces shown in Figure 2.14b.

Having established the passive pressure due to surcharge and cohesion with the unit weight of the soil set to zero these terms are now ignored, the soil given it's true unit weight and the passive force on the wall due to the soil calculated. This is exactly the same procedure as already described and is summarized in Figures 2.15a and 2.15b. The resultant passive force on the wall is given by summing forces PP1 and PP2.

2.4.6 Conclusions

From the four methods described the Rankine and Friction Circle Methods have been selected for use in the program. The Trial Wedge Method and Coulomb's Method were considered unsatisfactory.because of the very limited conditions under which the assumption of a plane surface of failure is justifiable

For the calculation of passive pressure the Friction Circle Method is used when the wall front is plane between the toe and front ground level. For all other cases Rankines Method is used to calculate the resultant passive pressure on a vertical plane passing through the toe and the resultant force on the wall found by combining this force with the weight of soil between the vertical plane and the face of the wall.

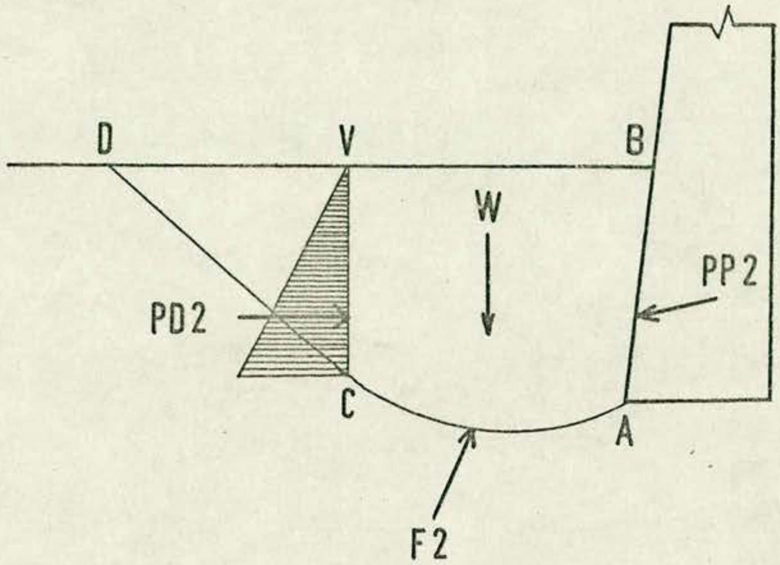


FIG. 2.15a. : CALCULATION OF PASSIVE PRESSURE IGNORING SOIL COHESION AND SURCHARGE

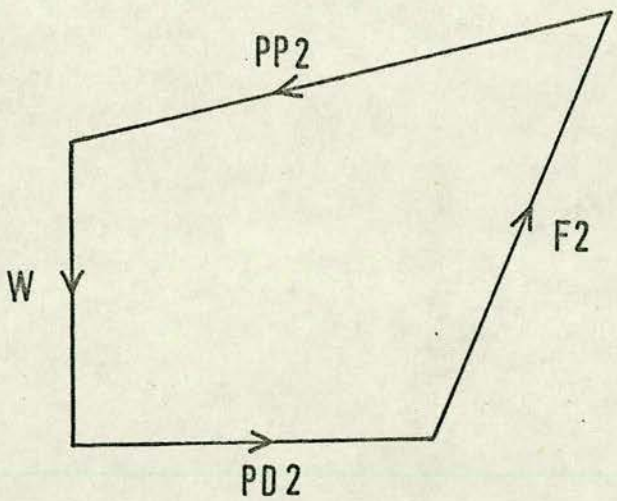


FIG. 2.15b. : POLYGON OF FORCES FOR CALCULATION OF PP2

CHAPTER 3

STABILITY ANALYSIS OF RETAINING WALLS

3.1 INTRODUCTION

The design of an earth retaining wall can be considered as essentially a two part process. Initially the overall dimensions of the wall have to be selected so that the wall, when considered as a whole, is stable.

Once these dimensions have been fixed the secondary stage of the design process involves the actual structural design of the various wall units i.e. for a cantilever wall the heel, stem, toe and key. In this program we are concerned solely with the primary design stage.

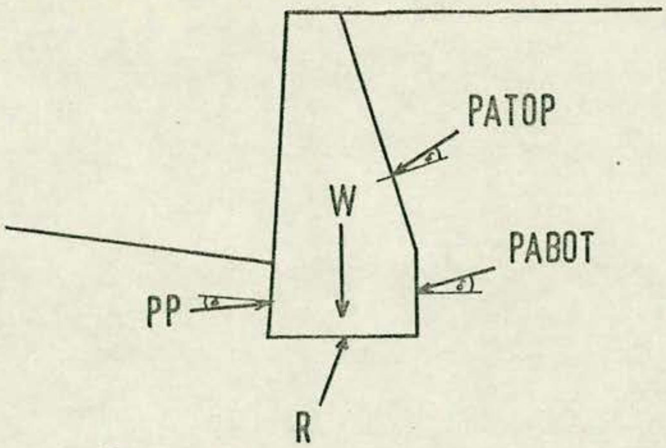
When considering the overall stability of the wall it is necessary to examine the stability of the wall against failure by sliding forward, overturning and bearing failure. In this chapter each of these failure modes will be considered and the procedure for estimating the stability of the wall against them described.

Before the wall stability can be examined the forces acting upon the wall will be discussed.

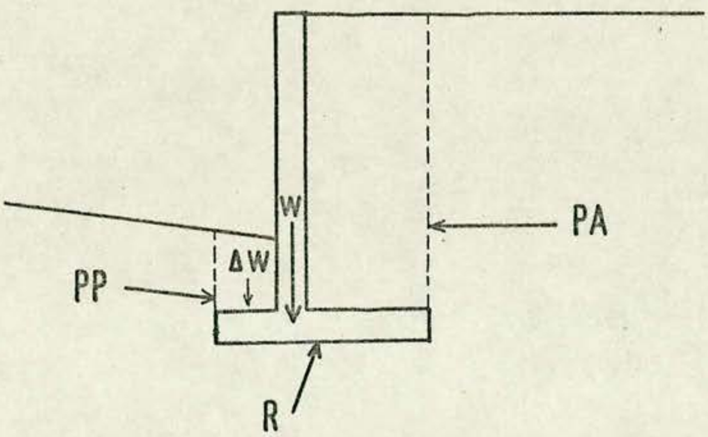
3.2 FORCES ACTING ON THE WALL

3.2.1 Introduction

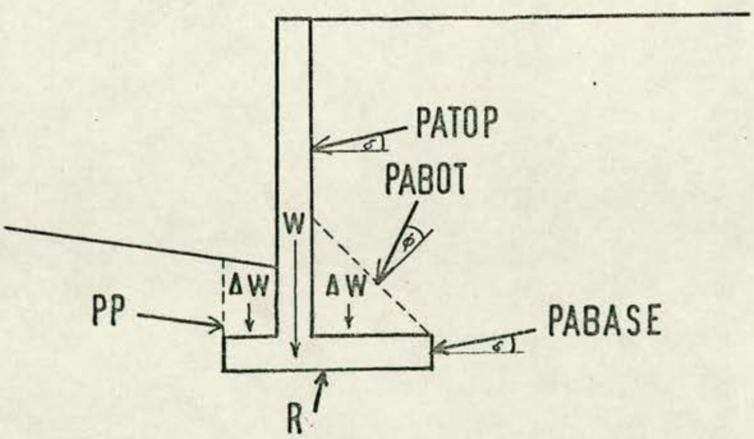
Before considering the question of wall stability a brief resumé of the forces acting on the wall is given. For the stability calculations it will be necessary to know not only the magnitude of these forces but also their points



a. gravity wall



b. cantilever wall with simple analysis



c. cantilever wall with included wedge analysis

FIG. 3.1. : FORCES ACTING ON A RETAING WALL

of application. While this is a fairly straightforward matter for most forces the resultant active earth pressure can prove troublesome.

The main forces acting on a retaining wall are shown in Figure 3.1

3.2.2 Wall weight

The self weight of the wall is the main stabilizing force in a gravity wall. Cantilever walls rely not only on their self-weight for stability but also on the weight of soil above the heel of the wall. The wall weight acts vertically downwards and through the centre of gravity of the wall.

3.2.3 Active earth pressure

3.2.3.1 General

The trial wedge method is to be used in the program to calculate active earth pressures. This method as discussed in chapter 2 (section 2.3.5) offers the considerable advantage of being able to cater for irregular backfill surfaces with any manner of surface loading. However while it will calculate the magnitude of the earth pressure the point of application may not be known.

3.2.3.2 Point of application of active earth force

When the ground surface is plane the distribution of the earth pressure across the wall back will be known (Figure 3.2a) and the point of application of the resultant force can be calculated. However where the ground surface

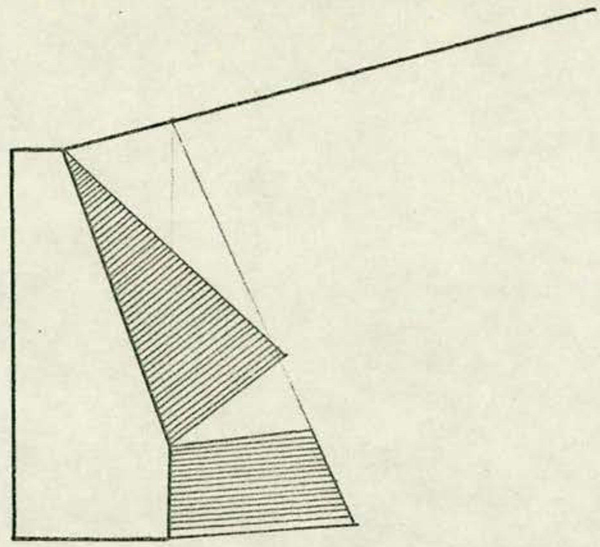


FIG. 3.2a. : PRESSURE DISTRIBUTION WHEN BACKFILL PLANE

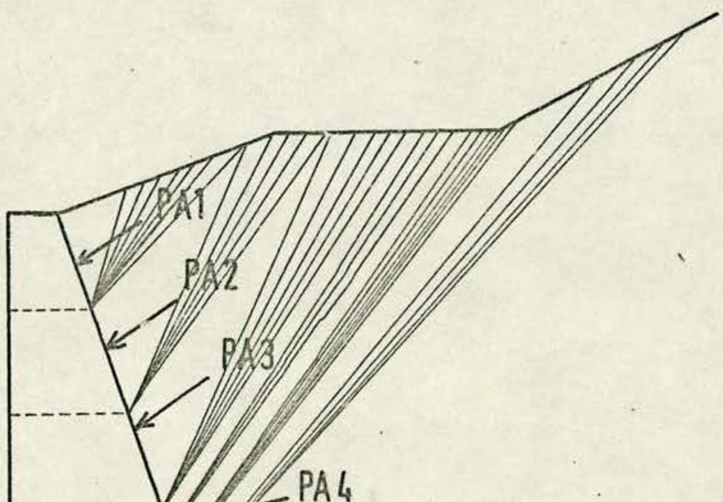


FIG. 3.2b. : TRIAL WEDGE METHOD WITH IRREGULAR BACKFILL

is irregular or contains some form of irregular loading the pressure distribution over the wall back will not be known.

This problem can be resolved by considering the wall back in a series of elements. If a state of plastic equilibrium has been established behind the wall any point on the wall back will represent the bottom of a potential surface of sliding. Therefore if the wall back is divided up into a series of elements (Figure 3.2b) the trial wedge method can be used to calculate the force acting on each wall section. The results of such an analysis can be plotted as shown in Figure 3.3a. Once the lateral force variation down the wall back is known the mean lateral pressure over each back element can be calculated using the relationship

$$p = \frac{PA(N) - PA(N-1)}{dh} \times \sin \omega$$

where $PA(N)$ = force on wall down to element N

$PA(N-1)$ = force on wall down to element N - 1

ω = angle of wall back with horizontal

dh = height of each wall element

Using this equation the earth pressure distribution over the wall back can be established from the values for the total earth force acting at various points down the wall. Once the pressure distribution has been established the point of application of the resultant earth force can be found because the resultant force will pass through the centre of gravity of the pressure distribution diagram. Figure 3.3b.

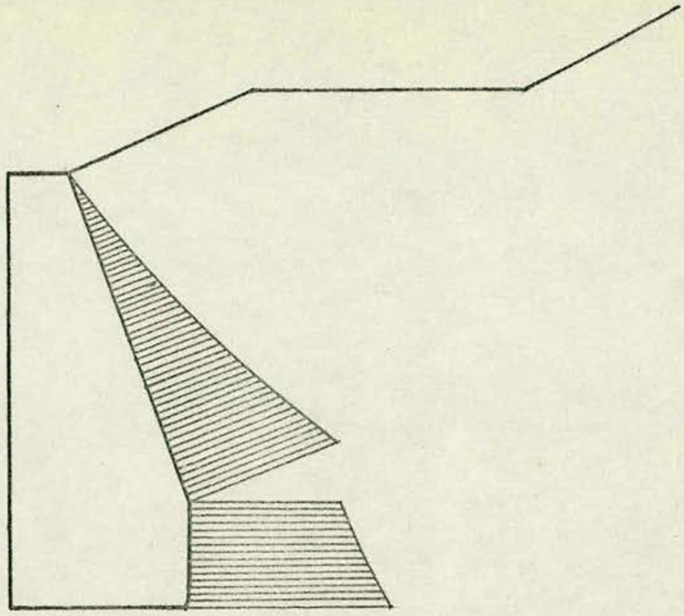


FIG. 3.3a. : NORMAL FORCE DISTRIBUTION ACROSS WALL BACK

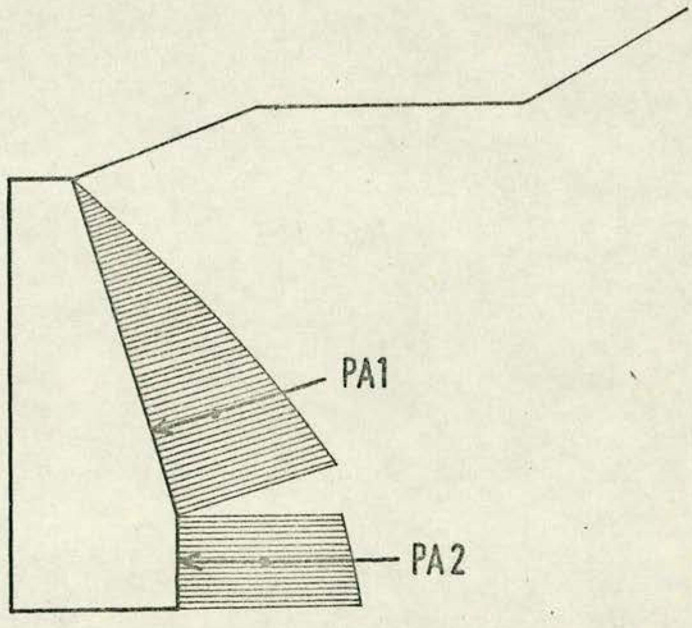


FIG. 3.3b.: PRESSURE DISTRIBUTION ACROSS WALL BACK

3.2.3.3 Gravity walls

The procedure for the calculation of active pressure on the wall will depend upon the shape of the wall back. Three types of wall back will be considered for analysis (Figure 3.4)

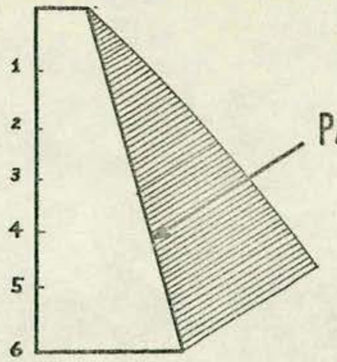
(i) Plane wall back:
the wall back is considered in six parts for the point of view finding the point of application of the resultant earth force.

(ii) Bi-planar wall back:
each part of the wall back is considered in three parts to establish point of application of the resultant force.

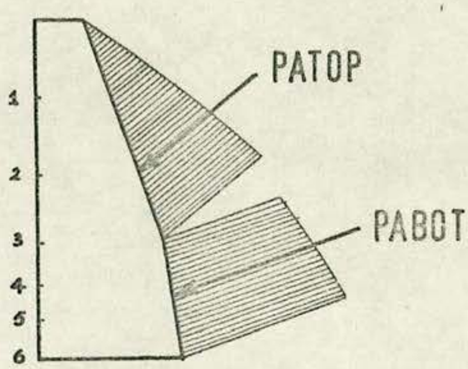
(iii) Bi-planar wall back with heel:
this is treated as described in (ii) with the heel portion considered as a single element on its own. The heel represents only a small part of the wall back and the pressure distribution over it is not considered. The earth force on the heel is assumed to act at it's mid-height.

3.2.3.4 Cantilever walls

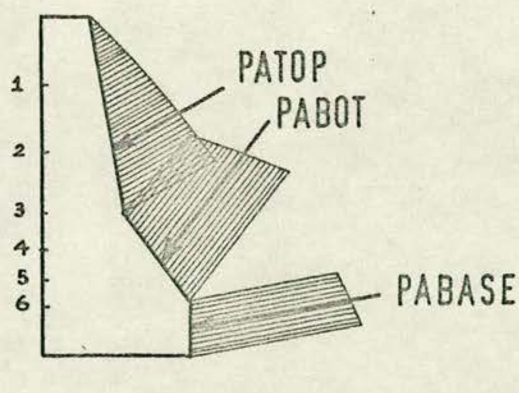
The analysis of the active pressure over the back of a cantilever wall is essentially similar to that used for a gravity wall once the surface upon which the pressures are to be calculated has been established. There are two methods used in the program for calculating the active pressure on the wall:-



a. plane back



b. bi-planar back



c. bi-planar back with heel projection

FIG. 3.4. : DIVISION OF BACK TO ESTABLISH PRESSURE DISTRIBUTION

(i) Simple analysis:

The analysis of cantilever retaining walls is generally accomplished by considering active earth pressures on a vertical plane through the heel of the wall. (Figure 3.1a). The point of application of the resultant force is found by carrying out a trial wedge analysis at several different levels down the vertical plane and thus establishing the pressure distribution over the surface.

A method for estimating the direction of the resultant pressure has already been described (chapter 2, section 2.3.5.3).

(ii) Included wedge analysis:

Model tests by Jenkin[11] showed that the true pressures measured on a retaining wall differed considerably from the pressures calculated by the method described above. Jenkin observed that an inner rupture surface formed between the top of the heel of the wall and the wall back. Sliding occurred along this surface with the wedge of soil between it and the wall back acting as if part of the wall and moving forward with the wall. Jenkin however gives no details of the position of this surface and apparently made no attempt to develop a method for the accurate calculation of earth pressures on such walls.

Terzaghi[27] suggests that as a first approximation the failure surface can be taken as making an angle with the heel projection corresponding to the Rankine outer plane of rupture i.e. $W_e = \{45 + \phi/2\} + \frac{1}{2}\{\epsilon - \alpha\}$ (Figure 3.1c) where ϕ = angle of soil friction, α = slope of backfill surface, and $\sin\epsilon = \sin\alpha / \sin\phi$. This approximation can of course only be used when the backfill surface is plane. However a more accurate solution can be obtained if several different shapes of included wedge surface are analysed i.e. AP1, AP2 etc in Figure 3.5. The true failure surface will then be the one which gives the maximum lateral pressure on the back of the wall.

If the angle the included wedge makes with the horizontal, We, falls below the angle of soil friction ϕ the assumption that sliding occurs along the included wedge surface is not justifiable.

For included wedge angles less than ϕ the frictional resistance along the assumed surface of sliding will be greater than the force tending to cause sliding. For this reason a lower limiting value of ϕ is enforced for the angle the included soil wedge makes with the horizontal. Figure 3.5

3.2.4 Passive earth pressure

As discussed in chapter 2 two methods are used in the program to calculate the passive earth pressure on the wall, Rankines Method and the Friction Circle Method. When the Rankine Method is used to calculate the passive pressure on a vertical plane through the toe, the pressure distribution over this plane is triangular and the resultant acts one

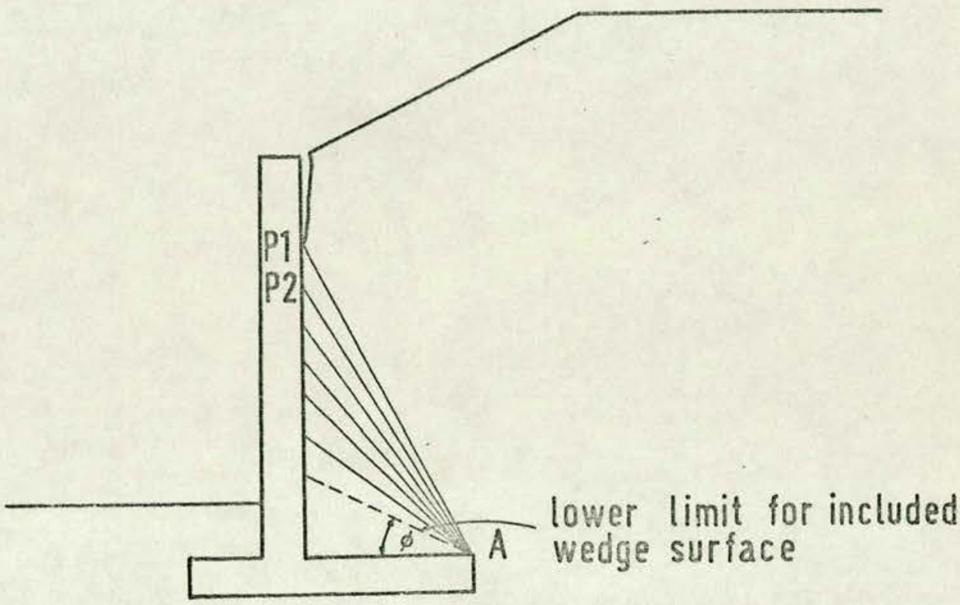


FIG. 3.5. : INCLUDED WEDGE SURFACES

third of the way up the plane and parallel to the ground surface. When there is a surcharge present the pressure distribution will be trapezoidal and the resultant will act through the centre of gravity of the pressure diagram. The resultant force over the wall can be found by combining the passive force with the weight of soil above the toe. However from the point of view of stability calculations it is simpler to keep the two forces in component form.

When the Friction Circle Method is used the resultant pressure will be given directly against the wall face. (Figure 3.1a). The pressure distribution will be triangular, or if there is a surcharge present trapezoidal. The resultant passive pressure will act through the centre of gravity of the pressure diagram and at obliquity δ to the normal to the face of the wall.

3.2.5 Water pressures

When there is a standing water level behind the retaining wall the water pressure on the wall will have to be established and included in the stability calculations.

For gravity walls the pressure distribution over the wall back will be as shown in Figure 3.6a. The water pressure increases linearly with depth and acts normally to the wall surface. The resultant force acts through the centre of gravity of the pressure diagram.

For cantilever walls the water pressures will act on three faces of the wall as illustrated in Figure 3.6b.

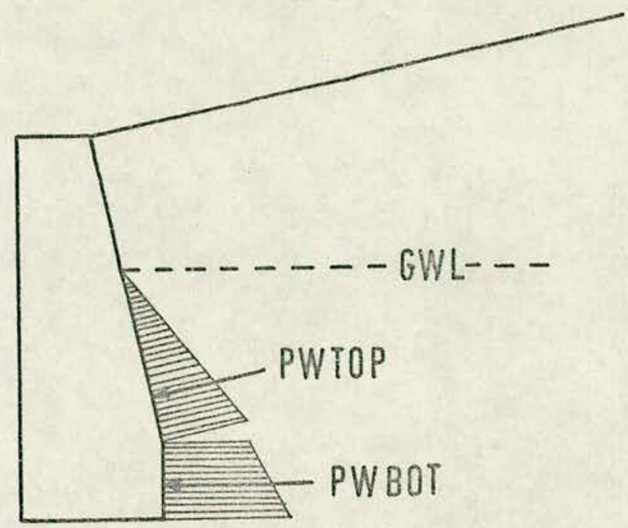


FIG. 3.6a. : WATER PRESSURE ON GRAVITY WALL

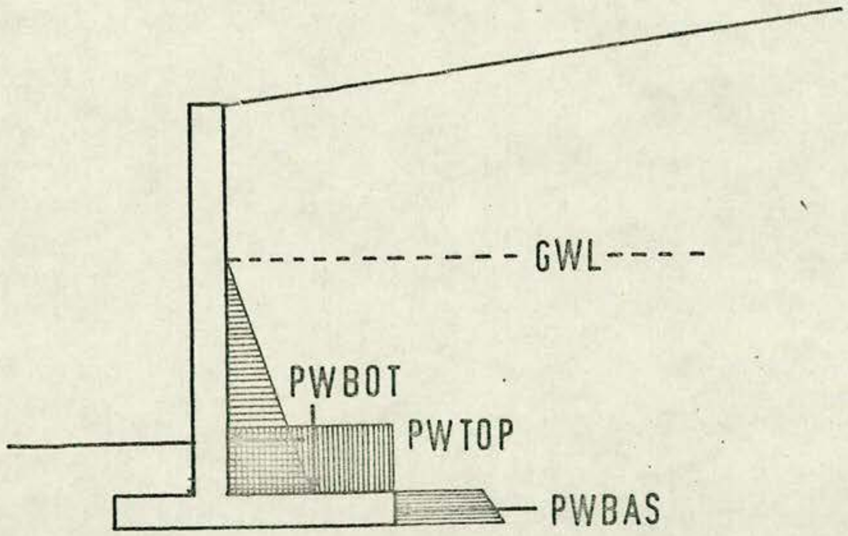


FIG. 3.6b. : WATER PRESSURE ON CANTILEVER WALL

3.2.6 Resultant force on base

The earth pressure is assumed to vary linearly over the base of the wall, and the resultant pressure on the base will act through the centre ofgravity of the pressure diagram.

The shape of the pressure diagram is dependent on the point of application of the resultant and is discussed in section 3.5.2.

3.3 FACTOR OF SAFETY AGAINST OVERTURNING FAILURE

3.3.1 Definition

The factor of safety of the wall against overturning can be defined as

$$\text{FSTIP} = \frac{\text{resistance of wall to overturning}}{\text{tendency of wall to overturn}}$$

The stability of the wall is generally assessed by taking moments about the toe, in which case

$$\text{FSTIP} = \frac{\text{stabilizing moment}}{\text{overturning moment}}$$

This definition is however open to several interpretations because it does not specify which forces on the wall are overturning forces and which are stabilizing.

Consider the wall shown in Figure 3.7. Using the definition of factor of safety given above and neglecting passive pressure

$$\text{FSTIP} = \frac{W_W \times \ell_W}{P_A \times \ell_p}$$

This equation for the factor of safety has the drawback that if the line of the active force intersects the base of the wall, the lever arm, ℓ_p, becomes negative and will give a negative factor of safety. A negative value for the factor

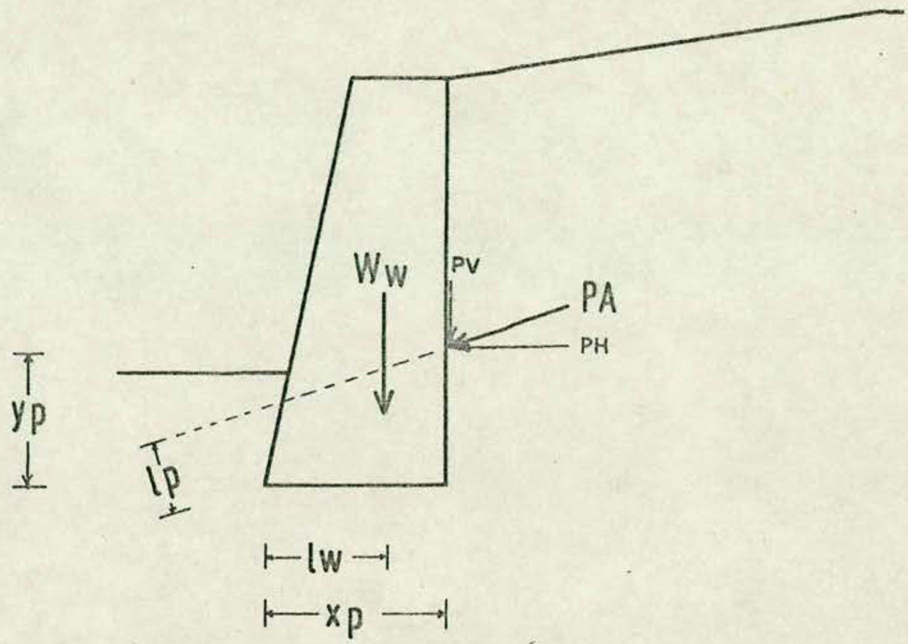


FIG. 3.7 : FORCES AND LEVER ARMS FOR FACTOR OF SAFETY AGAINST OVERTURNING

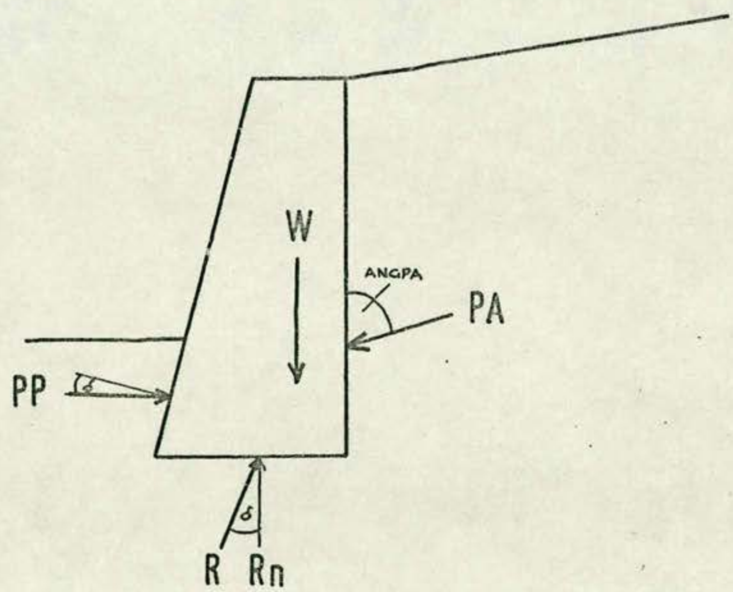


FIG. 3.8 : FORCES FOR CALCULATION OF FACTOR OF SAFETY AGAINST SLIDING

of safety would tend to suggest instability which is of course not the case at all. If the point of application of the active force on the back of the wall is known it would be easier to consider P_A in horizontal and vertical components when taking moments. This will avoid the necessity of calculating ℓ_p. When considered in component form, however, the resultant active pressure can be included in the stability equation in two ways:-

$$\text{FSTIP} = \frac{W_W \times \ell_W + P_V \times x_p}{P_H \times y_p} \qquad \text{Equation 1}$$

$$\text{FSTIP} = \frac{W_W \times \ell_W}{P_H \times y_p - P_V \times x_p} \qquad \text{Equation 2}$$

Of these two equations the first will always be positive. For a wall with a back inclined at a considerable angle to the vertical the denominator in the second equation may become negative giving a negative factor of safety. This of course does not mean that the wall is unstable in this particular case, however it may lead to confusion. The first equation is more consistent and more widely used, and will therefore be adopted for use in the program.

3.3.2 Alternative method for assessing stability against overturning

The equations for calculating the factor of safety given above are all developed for the assumption that overturning occurs about the toe of the wall. While the toe is a possible position for the centre of rotation it is only one of an infinite number of possible centres. Because the positio of the true centre of rotation is indeterminable certain authors[6,15] prefer to neglect the calculation of the factor of safety against overturning and consider an alternative restraint which will ensure stability against overturning.

The restraint used is that the resultant force on the base of the wall should fall within the middle third of the base. In other words the eccentricity of the resultant from the centre of the base should lie within the limits $\pm$ (base)/6.0.

When the resultant lies outside the middle third the large eccentricity will cause a marked non-uniformity in the pressure distribution beneath the base. When the wall rests upon a very compressible soil the non-uniform pressure distribution will cause differential settlement beneath the wall causing the wall to tilt forwards. Any forward tilting will cause a shift in the centre of gravity of the wall which in turn will lead to further increase in the pressure beneath the toe. This process may well lead to the eventual overturning of the wall.

The checking of overturning stability in this manner is closely tied up with the problem of bearing pressures and further consideration will be given to it in the section on bearing failure (section 3.5).

3.3.3 <u>Design value for factor of safety</u>

Generally, provided the resultant force lies within the middle third of the wall, the wall will be stable against overturning[6, 15, 22, 30]. However where the factor of safety against overturning about the toe is considered the wall should be designed so that a value of at least 1.5 is obtained[9, 25]. Karol[12] recommends that a minimum value of 2.0 should be used for cohesive soils.

3.4 FACTOR OF SAFETY AGAINST SLIDING FAILURE

3.4.1 Definition

The factor of safety of a wall against sliding failure can be defined as

$$\text{Factor of safety against sliding} = \frac{\text{forces resisting sliding}}{\text{forces causing sliding}}$$

For the wall shown in Figure 3.8 the factor of safety FSLID would be given by the equation

$$\text{FSLID} = \frac{\text{RN}.\tan\phi + \text{PP}}{\text{PA}.\sin(\text{ANGPA})}$$

The calculations of this factor of safety is far less controversial than the factor of safety against overturning. Although as will now be discussed the inclusion of passive pressure in the stability calculations is a matter of some debate.

3.4.2 Passive pressure contribution to stability

The development of passive pressure in front of the wall can assist considerably in maintaining stability of the wall against sliding failure.

However there are several factors that may prevent passive resistance from being fully developed. These are:-

(i) material may be excavated from in front of the wall in connection with future works

(ii) rainwater may cause soil above toe to be washed away

(iii) root holes in the soil may make it very compressible and mean that the forward movement necessary for the full development of passive pressure is prohibitive

(iv) freezing and thawing processes during winter may considerably soften the soil above the toe

Because of the effects of these factors passive pressure is sometimes neglected in stability calculations. However passive pressure forces can assist considerably in the maintaining of stability against sliding failure, and where measures are taken to avoid disruption by the above agencies passive pressure should be included in stability calculations.

The designer should consider the conditions affecting or likely to affect each particular design and use these as a basis to decide what proportion of the passive pressure should be used in stability calculations.

3.4.3 Angle of base friction

Retaining walls are generally concrete and are cast in-situ. Accordingly the base soil interface will be very rough. Sliding will not be possible along the interface because of the rougness but will occur through the soil immediately adjacent to the base.

The angle of friction that should be used when calculating frictional resistance along the base is therefore the angle of soil friction.

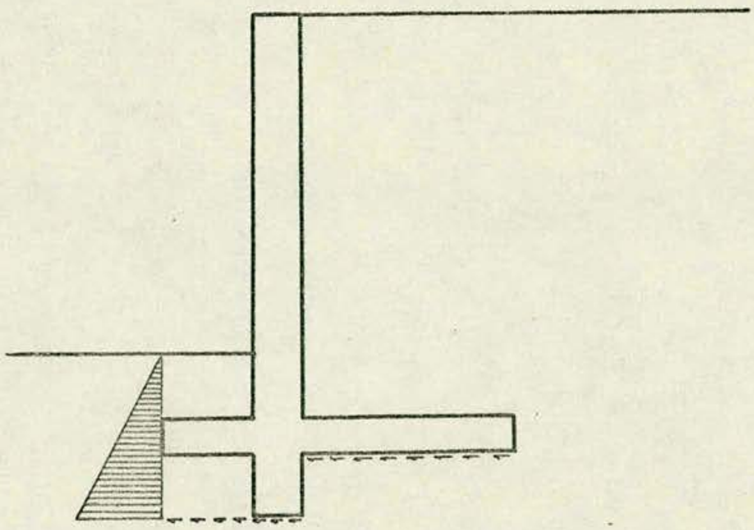
It will be found that it is often difficult to obtain the desired factor of safety when the foundation soil is clay because of the small angle of soil friction, especially when the soil is saturated. Under such circumstances cohesion beneath the wall may not provide sufficient resistance to sliding and the provision of a wall key should be considered.

3.4.4 Provision of a key to assist sliding stability

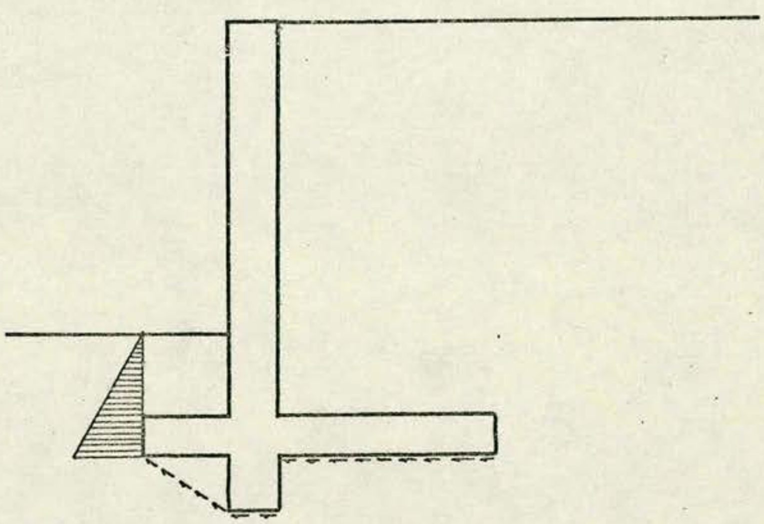
It will generally be found that for a sandy soil a wall which has been designed to be safe against overturning and bearing failure will also prove stable against sliding failure. However, as already stated, with clay soils this may not be the case.

Where additional sliding resistance is required this can be provided by sloping the base of the wall. This has the effect of increasing the magnitude of the resultant force on the base and at the same time increasing the obliquity the resultant makes with the vertical. Both the normal and tangential components of the resultant force now contribute to the resistance against sliding. This does however considerably increase the amount of material used in the base. A more efficient procedure is to provide a base key.

The base key is used to provide an increase in the amount of passive pressure that can be developed in front of the soil. However, as shown in Figure 3.9, unless the key



a. passive pressure fully developed



b. failure surface forms between toe and key

FIG. 3.9.: MODES OF SLIDING FAILURE FOR WALL WITH BASE KEY

is made reasonably deep a sliding plane may develop between the toe and the key. In such a case no additional passive resistance will be mobilized. While this is obviously not the desired result it does create an effective sloping base to the wall and will therefore give greater sliding stability than a wall base without a key.

Consequently when a base key is provided both failure modes shown in Figure 3.9 should be considered and the mode that provides less lateral resistance should be used to calculate the stability of the wall against sliding failure.

In Figure 3.9b the key was given an arbitary position on the base. It will be found in practice however that a heel key is the easiest to analyse.

A key at the toe of the wall is not very useful. It will ensure that the additional passive pressure is stabilized however it has the undesirable effect of changing the position of the effective toe of the wall. This will adversely affect the factor of safety against overturning, because of the increase in lever arm for the active forces.

When the key is positioned between the toe and heel of the wall the calculation of sliding stability becomes complicated. For such a wall shape the consideration of stability when a failure plane develops between the toe and heel requires that an effective base made up of two planes be considered. For this case while the resultant force will be known its direction of application will not.

The most convenient place for the key is at the heel of the wall. Now when considering stability when a failure plane develops between the toe and the key, the effective wall base can be taken as AB (Figure 3.10) and the part at the bottom of the key BC neglected.

Provision will be made in the program to include a heel key in the wall design.

3.4.5 Design value for factor of safety

A factor of safety of between 1.50 - 2.00 will be required when considering sliding stability of the wall.

Code of Practice No 2 [6] recommends a value of 1.50 should be used when passive pressure is neglected but that this should be increased to 2.00 where passive pressure forces are included. This will make allowance for factors that may prevent the passive resistance from being fully stabilized. Both Teng [25] and Logeais [15] recommend a minimum factor of safety of 1.50.

Bowles [4] recommends a value of 1.50 for cohesionless soils but suggests that this should be increased to 2.00 for cohesive soils because of the possibility of cohesive strength and angle of friction being adversely effective by the presence of water.

3.5 FACTOR OF SAFETY AGAINST BEARING FAILURE

3.5.1 Definition

The maximum bearing pressure that the soil can withstand without failing by shearing or showing excessive settlement is the ultimate bearing capacity of the soil. The allowable bearing capacity of the soil is found by dividing the ultimate bearing capacity by an appropriate factor of safety.

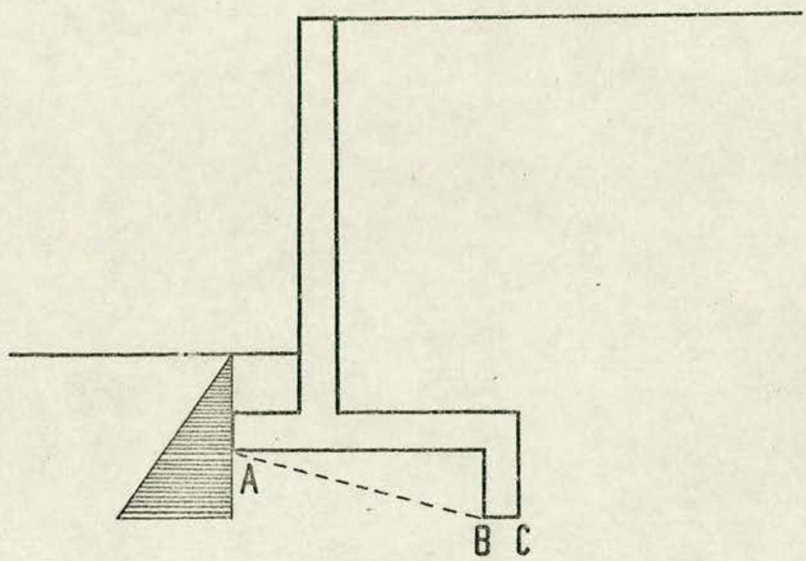


FIG. 3.10. : CANTILEVER WALL WITH HEEL KEY

Code of Practice No 2[6] suggests that a factor of safety of 2.0 should be used for cohesionless soils and 3.0 for cohesive soils.

The factor of safety against bearing failure can be defined in terms of the allowable bearing capacity as

$$FSBCY = \frac{\text{allowable bearing capacity}}{\text{maximum bearing pressure beneath base}}$$

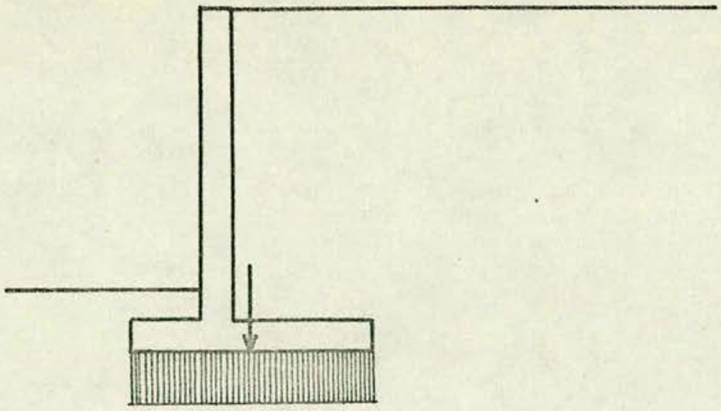
Provided this factor of safety is greater than 1.0, irrespective of the soil type, the wall should be stable against bearing and settlement failure. This method of defining the factor of safety differs from the methods used for the factors of safety against overturning and sliding. However it has been adopted so that irrespective of soil type a constant design factor of safety of 1.0 can be used during the design process.

3.5.2 <u>Pressure distribution beneath wall</u>

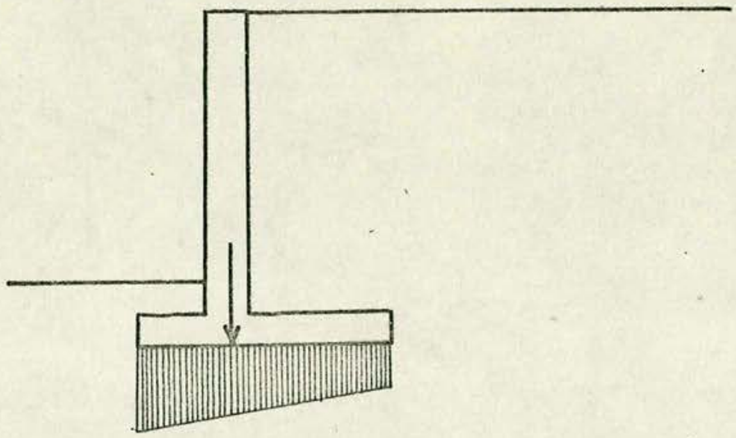
Before the maximum bearing pressure beneath the base can be found the pressure distribution beneath the wall must be ascertained. The pressure distribution over the base will be one of three forms depending upon the position of the point of intersection of the resultant with the wall base. The three cases considered are:-

(i) If the resultant force strikes the centre of the base, the earth pressure is uniformly distributed over the base. Figure 3.11a. This is the most acceptable condition because uniform pressure distribution will lead to uniform settlement.

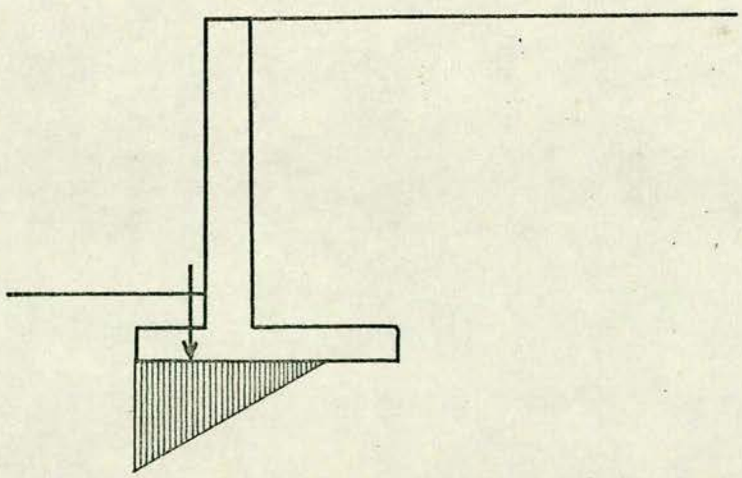
$$p = \frac{R_N}{B}$$



a. resultant intersects centre of base



b. resultant lies within middle third of base



c. resultant lies within outer third of base

FIG. 3.11. : DISTRIBUTION OF NORMAL PRESSURE BENEATH WALL

(ii) When the resultant force lies within the middle third of the base there will be a linear distribution of pressure over the whole base. Figure 3.11b. For this case the bearing pressure at the extremities of the base will be given by

$$p = \frac{R_N}{B} \left\{ 1 \pm \frac{6e}{B} \right\}$$

(iii) When the resultant force falls outside the middle third there will be no pressure under the heel. Figure 3.5c. The pressure distribution over the base will be triangular as shown and the magnitude under the toe will be

$$p_T = \frac{2\ R_N}{3\ B}$$

This case is most undesirable and should only be accepted when the wall is to be founded on rock.

3.5.3 Calculation of allowable bearing capacity

Having established the maximum bearing pressure beneath the wall, before the factor of safety can be calculated it is necessary to find the allowable bearing pressure. The value for the allowable bearing pressure will depend upon the depth at which the wall is founded, the width of the base and whether the soil is cohesive or cohesionless.

The following ammendments, as recommended in C.P.2[6], are made to the initial value of the allowable bearing capacity:

(i) if the foundation material is cohesionless and the base less than 3' 0", or 1.0 m, the allowable bearing capacity is reduced by a factor BASE/3.0 ft (BASE/1.0m)

(ii) if the foundation is cohesionless and the wall founded at a depth D below ground level the allowable bearing capacity is increased by a factor

$$\frac{1.0 + \text{DEPTH} - 2.0^*}{\text{BASE}}$$ *1.0 for metric unit

(iii) if the foundation soil is cohesive and the wall founded at depth D below ground level the allowable bearing capacity is increased by a factor

$$\frac{1.0 + \text{DEPTH} - 2.0^*}{4.0^* \ \text{BASE}}$$ *1.0 for metric unit

Once these factors have been applied to the initial value of bearing capacity the value arrived at for the allowable bearing capacity is checked against a limiting value for the term. Under no circumstances should the amended value exceed 1.50 times the initial value for cohesive soils.

For cohesionless soils this restriction is not put on the value of the allowable bearing capacity. Instead it is left to the designer to assess the conditions likely in the field and to fix a value for the maximum bearing capacity. This value is input as part of the initial data.

If the amended value for the allowable bearing capacity is found to exceed the maximum permissible value for this term (found as described above) the allowable bearing capacity is reduced to the maximum permissible value.

3.5.4 Wall settlement and tilting

A certain amount of wall tilt is desirable so that the soil behind the wall can expand laterally and attain an active state of stress. However model analyses (Terzaghi [27], Jannson et al [10]) have shown that the movement required is small being of the order of 0.001 - 0.005 times the wall height.

The base pressures should be such that the differential settlement of the wall between toe and heel does not exceed that necessary to produce the required tilting.

Where the wall rests on a saturated sand or gravel settlement will be relatively quick because such soils have a high permeability. However the percentage voids is relatively low for such soils especially if well graded and compression settlement will be small. For such soils most of the expected settlement should be complete by the time the wall construction and backfilling process have been finished.

When the wall rests on a very compressible soil, i.e. saturated clay, compression will take place very slowly because of the time required to displace the porewater. In such cases consolidation may continue for several years. Where there is an uneven distribution of pressure under the base with greater pressure at the toe than under the heel the wall will gradually tilt forwards. This process may eventually lead to the overturning of the wall.

Consequently where the wall rests on a very compressible soil it should be designed so that the resultant force lies close to the centre of the base.

3.6 PROGRAM CALCULATION AND OUTPUT OF FACTORS OF SAFETY

The stability of the wall is assessed by calculating three factors of safety as described in the preceeding sections. The factors of safety are output on the screen along with a drawing of the wall cross-section as shown in Figure 4.11.

In addition to calculating a factor of safety against overturning the position of the resultant force on the base of the wall is found and marked with an arrow (Figure 3.14). This will provide additional assistance for the designer when considering soils which are particularly compressible.

As will be discussed in chapter 4 (section 4.4.4.3) the amount of the available passive pressure to be used in the stability calculation can be controlled by the user. This will enable the designer to make allowance for any factors that may prevent the passive pressure from being fully developed.

When the included wedge analyses method is used for analysing a wall,as discussed in section 3.2.3.4,several possible included wedge shapes are considered. For each failure shape the resulting forces on the wall are calculated and the wall stability analysed.

The final factors of safety for the wall are then taken as the lowest values for each factor of safety found during the analysis of the various shapes of included wedge. The final factors of safety therefore do not all necessarily refer to the same failure shape, however they will represent the critical cases for each mode of failure.

CHAPTER 4

THE APPLICATION OF COMPUTERS TO RETAINING WALL DESIGN

4.1 INTRODUCTION

Computers have proved successful in many fields not because they can perform tremendous feats of high powered calculation but because they can perform simple operations very quickly.

Computers are especially useful for design calculations where any form of iterative process is used and where it is necessary to work through a specified set of calculations many times varying perhaps only one piece of data at a time.

The calculation of active pressure by the Trial Wedge method and passive pressure by the Logarithmic Spiral Method are operations of this nature and are therefore ideally suited to computer programming. The calculations involved in the finding of earth pressures on the wall are not difficult however they are fairly lengthy. For anything but the simplest case the calculations are tedious. If conditions are complex, for example for a wall with broken back and an irregular ground surface, the work involved would be quite prohibitive.

Consequently without computer assistance the designer is severly limited in both the type and number of designs he can consider. The wall shape must be selected preferably to permit use of a Rankine or Coulomb equation for calculating earth pressures or failing this a shape that can be analysed without too much complication by the Trial Wedge Method or one of its graphical substitutes. Such a design is obviously limited in scope and the resulting wall section will not necessarily be very economical.

A computer program which offers a versatile analysis process can relieve the designer of the restrictions which surround manual analysis and allow him to try more adventurous wall shapes which will, hopefully, provide a more economical design.

4.2 COMPUTER SYSTEMS

4.2.1 General

Before giving a description of the system on which the program is to be run a short note will be given on computer systems in general.

Three basic computer systems can be identified:-

(i) Batch system:

The user sends his program and data to the computer. Here the jobs to be run are queued-up and fed into the machine in batches. The results are returned to the user upon completion of the job.

Such a system will naturally have an inherent delay between the dispatch of the job and the return of the results. Where a large amount of data has to be processed and where the results will require fairly lengthy analysis, for example frame analysis programs, such a system may be quite acceptable. However where the design process is fairly rapid, and where alterations will be necessary in the light of previous results, such a system will be both inefficient and frustrating.

(ii) Dedicated system:

There are obvious advantages in having direct access to your own machine, however this may prove a costly business. Where a machine is required for a specific purpose and the size of program to be run is small the purchase or lease of a mini-computer may prove an ideal solution.

However where large programs are to be run the cost of purchasing, or even leasing, a suitable machine will generally prove quite prohibitive.

(iii) Timesharing system:

A timesharing system can offer just about all the benefits of a dedicated system but at a fraction of the cost. Under such a system a number of users have access to the machine at the same time. The machine time is divided up into time slices and each user in turn given his share of machine time. Under such a system the machine time is shared but because the time slices are very short and the machine operates very quickly it appears to the user that he has a dedicated system.

This is the system under which many computer bureaus work and individual users of the system can operate from remote terminals linked to the machine via G.P.O. lines.

4.2.2 C.A.D. computer system Edinburgh University

4.2.2.1 Introduction

A diagramatical representation of the computer system in the Computer Aided Design Project at Edinburgh University is given in Figure 4.1. The retaining wall design program is written to be run on this system via a Tektronix 4010-1 display terminal and uses the Sturgeon graphics package developed by Spring[22] of the Architectural Research Unit at Edinburgh University.

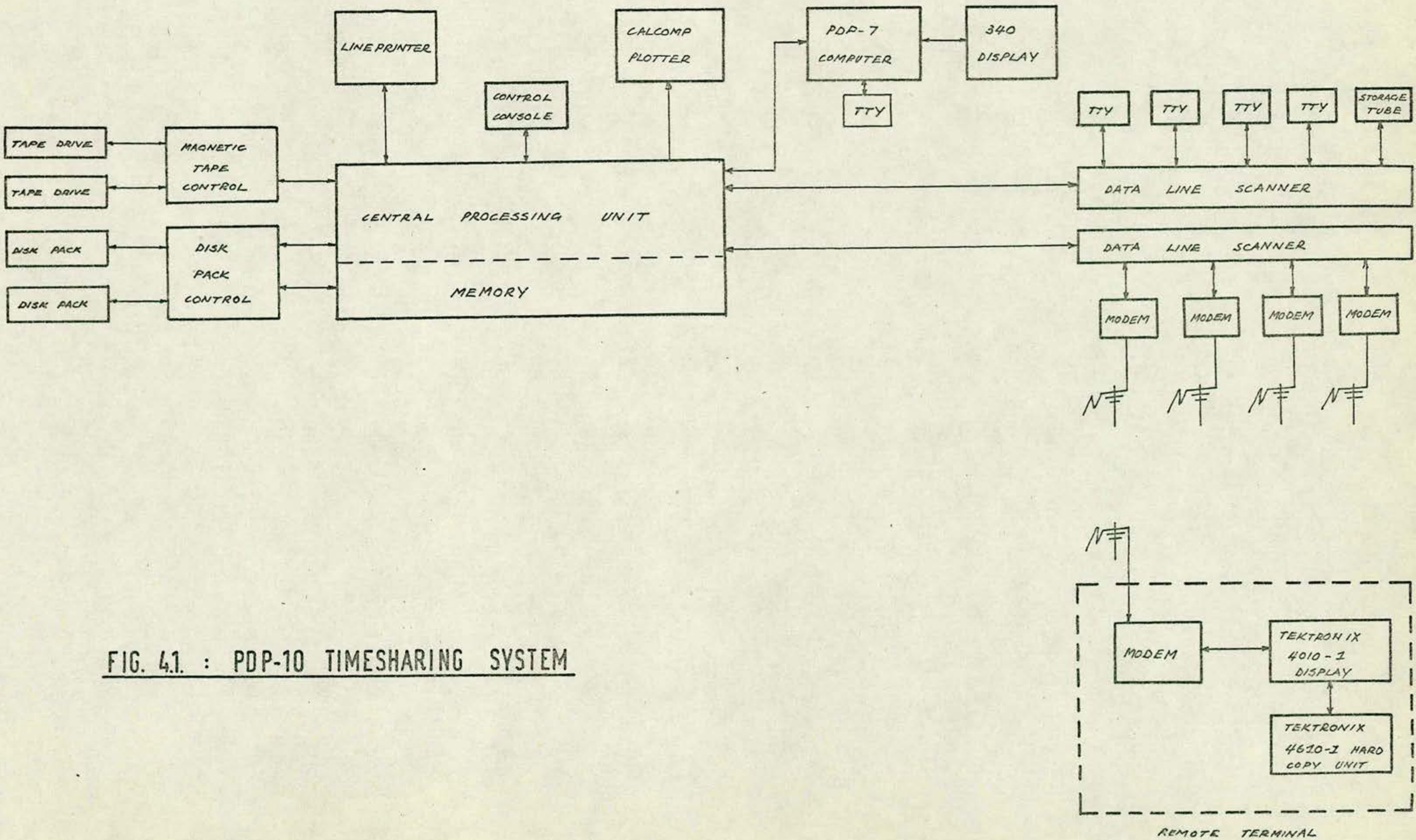


FIG. 4.1. : PDP-10 TIMESHARING SYSTEM

4.2.2.2 Central processing unit[17, 18]

The central processing unit is the central unit for the system, and governs all peripheral I/O equipment. The CPU is also responsible for sequencing the program and for performing all arithmetic, logical and data handling operations. The processor is connected to the memory unit by a memory bus and to the peripheral equipment by an I/O bus. The disks, although controlled by the central processor over an I/O bus, have direct access to memory over a second bus.

4.2.2.3 Backing storage

(i) Disks:

The disks are the largest random access storage devices in the system and provide the fastest storage outside the core. The disk packs are used for both permanent and temporary storage. Each system user is allocated a certain amount of disk space for the storage of his programs and data files. This can be regarded as permanent storage.

During the running of the timesharing system jobs are continually swapped in and out of core with the disks being used as temporary back-up storage while jobs await return to core. Output from programs via slow peripheral devices, such as lineprinter and paper tape punch, is stored temporarily on disk while awaiting access to the peripheral devices.

(ii) Magnetic tapes:

Magnetic tapes can be used as back-up storage for memory however because of the length of time required to access data on tapes they are only really suitable for storing data that need not be available to the system continuously.

In the CAD system the magnetic tapes are used to keep back-up copies of material stored on the disks and can be used to retrieve files that are lost from the disk due to accidental deletion or in the event of a system failure.

4.2.2.4 Primary Input/Output devices

(i) Paper tape reader and paper tape punch:

The paper tape punch produces 8-channel fan-fold tape at a speed of 50 lines/sec. The output can be in either alphanumeric or binary mode.

The paper tape reader will read-in 8-channel paper tape photoelectrically at a speed of 300 lines/sec.

(ii) Lineprinter:

The lineprinter is the fastest device for text output and produces hardcopy at the rate of 600 lines/minute with a maximum of 132 characters per line.

The standard lineprinter paper has 11 inch pages each comprising 66 lines. With a spacing of 3 lines at the top and bottom of each sheet 60 lines of output are available per page.

4.2.2.5 Communication devices

User communication with the system is generally via teletype. Six teletypes are available in the machine room and these are connected directly to the PDP-10.

There are however several remote terminals one of which is located in the Civil Engineering Department. Three devices comprise the remote terminal:-

(i) Modem:

The remote terminal is linked to the PDP-10 via a G.P.O. line. To use the phone line as a link to the computer the output from both the computer and the terminal must be converted into a signal suitable for transfer via phone line. A modem (modulator-demodulator) is required therefore at both ends of the line, one to convert the output into a suitable signal and the other to reconvert the signal into a form suitable for input to computer and terminal.

(ii) Tektronix 4010-1 display terminal:[24]

The display terminal comprises simply a keyboard and display screen. The screen is a cathode ray tube with a special phosphor coating on the inside. When a picture is transmitted to the screen a permanent charge distribution is set up on the screen by an electron beam. This picture will remain on the screen and can only be removed by flooding the whole screen with electrons. This is an important feature of this type of storage tube display. While it is possible to add to an existing display it is not possible to selectively delete parts of the display. If any part of the picture has to be removed or altered the whole screen must be erased and the picture redrawn from scratch. (c.f. refreshed display where the picture is redrawn many times per second and selective deletion is possible).

The screen has a working area of $7\frac{1}{2}$" x 5" and when in alphanumeric mode can display 35 lines of information with a maximum of 72 characters per line.

In graphics mode the screen can be considered as being made up of a grid of addressable points. 1024 x 780. Any point on the screen can be identified by means of a graphics cursor which is made up of two cross-hairs one horizontal the other vertical. When displayed the cursor can be moved about by using two thumbwheels provided on the terminal keyboard.

(iii) Tektronix 4610-1 Hard Copy Unit[25]

The considerable advantages of a display terminal over a conventional teletype terminal (section 4.2.3.2) would be considerably reduced if it was not possible to obtain a hard copy of the display. The 4610-1 Hard Copy Unit produces a copy of the display on paper $8\frac{1}{2}$" x 11" and is activated by depressing the MAKE COPY switch on the control panel of the display terminal.

One hard copy unit can be used to serve up to four display terminals.

4.2.3 Interaction graphics

4.2.3.1 Interaction programming

The program developed for retaining wall design can be regarded as an interactive graphics program. The term interactive means simply that the user has the ability to communicate with the program during its running.

The advantages offered by such a system over a batch system program are considerable. The user can now take command of the design process and direct the search for a suitable wall shape.

From the results of the initial analysis the designer, using his experience and judgement, can make changes to the wall shape and then call for immediate analysis of the amended section. By repeating this process it should be possible to mould the original wall shape into a final design.

Such a design procedure is considerably faster than the equivalent procedure that would be necessary under a batch system, where there would be a delay of as much as a day between the dispatch of the program and the return of results for each trial design.

Interactive programming therefore transforms the design from a lengthy disjointed procedure into a short continuous process.

In addition to speeding up the design process interactive programming should permit greater efficiency in the design process. Under a batch system the user in an attempt to speed-up the design procedure may submit several wall shapes for analysis at the one time. While it may be possible to incorporate some form of selection procedure over which shapes are analysed this will at the best be a rather crude affair and in no way match the control possible in the interactive system. The net result is that many sections which would be rejected by the user under the interactive system may be analysed needlessly under the batch system. It is possible therefore to obtain a greater efficiency with an interactive program.

4.2.3.2 Computer graphics

The advantages offered by an interactive computer system for retaining wall design can be further enhanced by the introduction of computer graphics facilities.

The obvious advantage of replacing a conventional teletype with a visual display unit is that the user now has the facility for outputing drawings in addition to alphanumeric information. The scope of the graphics will of course depend on the software available.

Another advantage offered by a display terminal is the increased speed at which alphanumeric information can be output. On average the speed of writing is at least 10 times faster for a storage tube display terminal than a conventional teletype terminal. This will of course be particularly advantageous where a large amount of data has to be output as results.

The visual display unit is also silent - this does not directly affect design time or design efficiency however it does make the operation less tiresome for the user.

To return to the principal benefit of a display screen, namely graphical output, it will be found that retaining wall design is well suited to graphics. When designing a wall an engineer will work from drawings and sketches. With a program offering computer graphics the designer can still work from drawings and the interactive facilities can now assume the form of graphical interaction. The designer can now communicate with the program directly via a wall shape rather than by an abstract set of co-ordinates.

There is one final point about computer graphics that is often overlooked - this concerns the question of obtaining a permanent record of material displayed on the screen. The considerable advantages offered by a visual display described above will be rather diminished if at the end of the analysis process the designer has to manually copy the results from the screen. To obtain full benefit from the graphics facilities it must be possible to make a hard copy of the display at any time during the running of the program.

4.3 A SURVEY OF EXISTING RETAINING WALL PROGRAMS

4.3.1 Introduction

A brief description will be given of six programs for retaining wall design. These programs vary considerably in their scope however they tend to be rather limited in their application.

Only one program offers user interaction facilities, and none of the programs involve computer graphics.

Most of the programs were written before timesharing systems became generally available and are therefore designed for batch processing.

4.3.2 Wadsworth

Wadsworths program[30] is for both the primary and secondary design of cantilever retaining walls. The program is run under a batch system.

Active earth pressures are calculated by one of three methods depending upon the soil properties and backfill profile

The methods used are Rankine's, Trial Wedge and Equivalent Fluid. Passive earth pressures are not considered.

The program will analyse various heights of wall as specified by the designer. For each wall height the program uses an optimising technique to find the most suitable base width. The optimising technique comprises the following stages (Figure 4.2):-

(i) <u>Set initial values</u>:

Toe width is initially set to 0.5 ft and the heel to one tenth of the wall height.

(ii) <u>Compute FSLID</u>:

If FSLID falls below design requirement increase length of heel until design factor of safety achieved.

(iii) <u>Compute FSTIP</u>:

If FSTIP falls below design requirement increase length of toe until design factor of safety achieved.

(iv) <u>Compute FSBCY</u>:

Increase toe length until design value achieved.

(v) <u>Re-check value of FSLID</u>:

If the toe length was increased at stages (ii) and (iii) the heel might now be unecessarily long. If FSLID greater than design requirement reduce heel until factor of safety just satisfied.

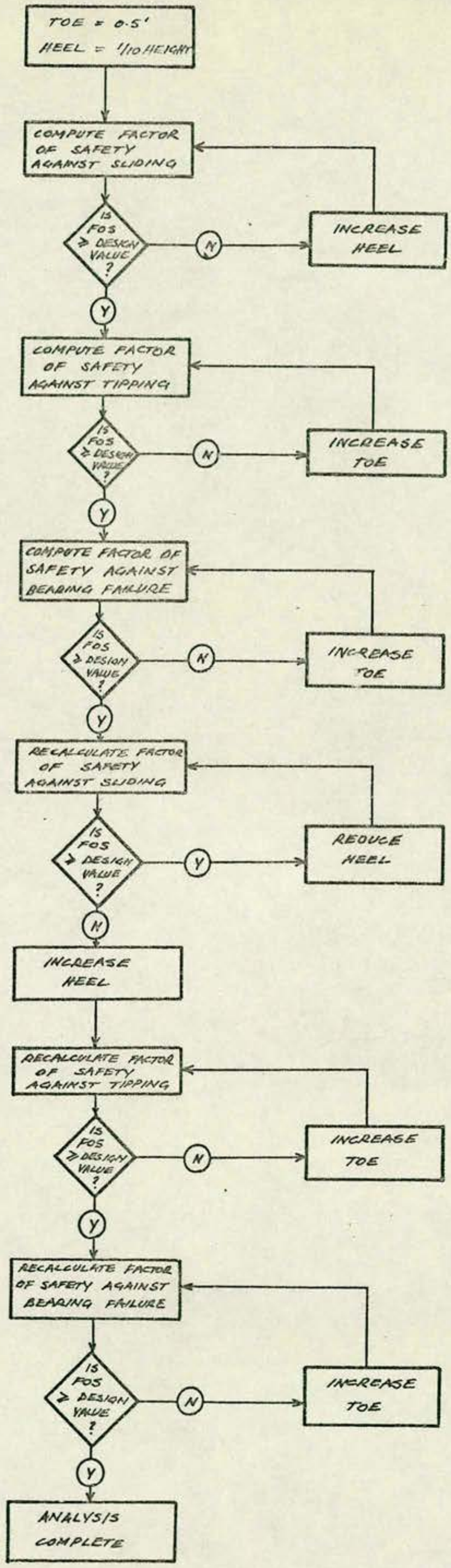


FIG. 4.2.: FLOW DIAGRAM FOR WADSWORTH'S ANALYSIS PROCEDURE

(vi) Re-check value of FSTIP:

Increase toe length if necessary.

(vii) Re-check value of FSBCY:

Increase toe length if necessary.

(viii) Analysis complete

The program can deal with a bi-linear backfill surface provided the part further from the wall back is horizontal. No surcharge loads are permitted on the backfill surface.

4.3.3 Puroshothaman

Purushothaman acknowledges that no attempt was made to produce a program that would be generally applicable to retaining wall design[19].

The program was written to cater specifically for the design of cantilever walls supporting horizontal deposits of cohesionless soil. A continuous uniformly distributed load can be included.

Active earth pressures are considered on a vertical plane through the heel of the wall and are calculated directly by Rankine's equation.

No provision is made for calculating passive earth pressure in front of the wall.

4.3.4 Knapton

Knaptons program[13/14] appears to be one of the few programs for the interactive design of retaining walls. The program can be used to design both the overall wall dimensions of cantilever walls and the structural design of the various elements of the wall. The interaction provided is on a fairly limited scale and is primarily concerned with the structural design part of the program.

A variety of analysis methods are incorporated in the program for both active and passive pressure calculation. The method chosen for stability calculations is dependent upon the soil properties of the backfill and whether or not it is horizontal.

Active pressures are calculated on a vertical surface passing through the heel.

A flow diagram outlining the primary design stage is given in Figure 4.3. It will be seen that this incorporates a method of finding an optimum arrangement of wall dimensions by considering various toe:base ratios.

One of the additional features available to the designer with this program is the provision of a heel key. The inclusion of a key at the heel of the wall is assumed to increase the amount of passive pressure that can be mobilized. The method for calculation of the additional passive pressure is not given in detail however as is discussed in chapter 3 care has to be exercised when considering the additional resistance that can be developed by a base key.

The program has apparently been run via both a conventiona teletype and a visual display unit. However there does not appear to be any form of graphical display or graphical interaction included in the program, the display unit being used simply as a fast teletype.

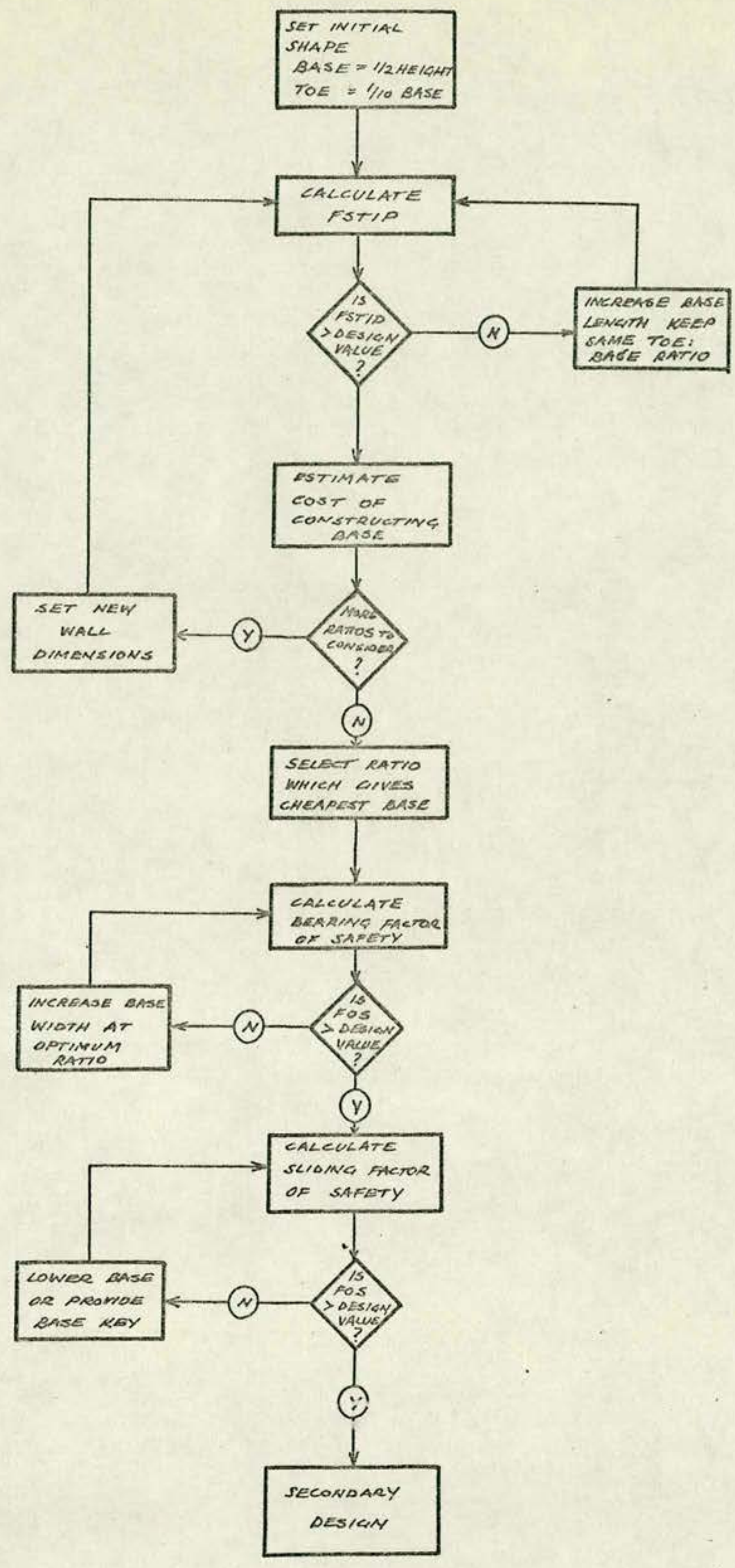


FIG. 4.3.: FLOW DIAGRAM FOR KNAPTON'S PRIMARY DESIGN

4.3.5 Schimming and Fischer

This program is more an exercise in the application of optimization techniques and a comparison of their efficiencies than an attempt to produce a general retaining wall design program.

The paper by Schimming and Fischer[21] discusses in some detail the various optimization techniques used however it gives no mention of the procedure used for calculating active or passive earth pressures.

An examination of the input data required for the program suggests that the program is restricted to the analysis of cantilever retaining walls with a cohesionless backfill that has a plane surface. The analysis will therefore most probably be carried out by using Rankine's equation to find the active pressure on a vertical plane through the heel.

4.3.6 Carsen

A program for retaining wall design is mentioned as part of a general discussion on the application of computers to civil engineering problems[5]. Carsen's program is for the design of cantilever retaining walls and appears to be fairly comprehensive. The program can cater for any shape of backfill with any form of surface loading, and can be used for walls resting either on foundation material or piles. No details are given of the methods used for calculating earth pressures.

4.3.7 Aitkens program

A very comprehensive non-interactive program which caters for both the primary and secondary design stages for cantilever retaining walls[1]. The program can cater for an irregular backfill surface with up to four surcharge loads.

Active pressures are calculated on a vertical plane through the heel of the wall using the Trial Wedge Method. No attempt is made to calculate the position of the resultant active pressure on this surface it is simply assumed to act one third of the way up the surface.

Passive pressures in front of the wall are calculated by Rankine's Method.

The program incorporates an optimization technique which will find the minimum base width which will satisfy the stability requirements. This technique is outlined in Figure 4.4.

The program will consider several different toe widths however it is limited to the consideration of only one toe depth.

Provision is made for the inclusion of a base key under the heel of the wall.

4.3.8 Summary

The programs discussed here cover a wide variety of approaches to retaining wall design. Only one program however offers interactive design (Knapton). The scope of the designs is dependent largely upon the methods used for calculating the active earth pressure. Where provision

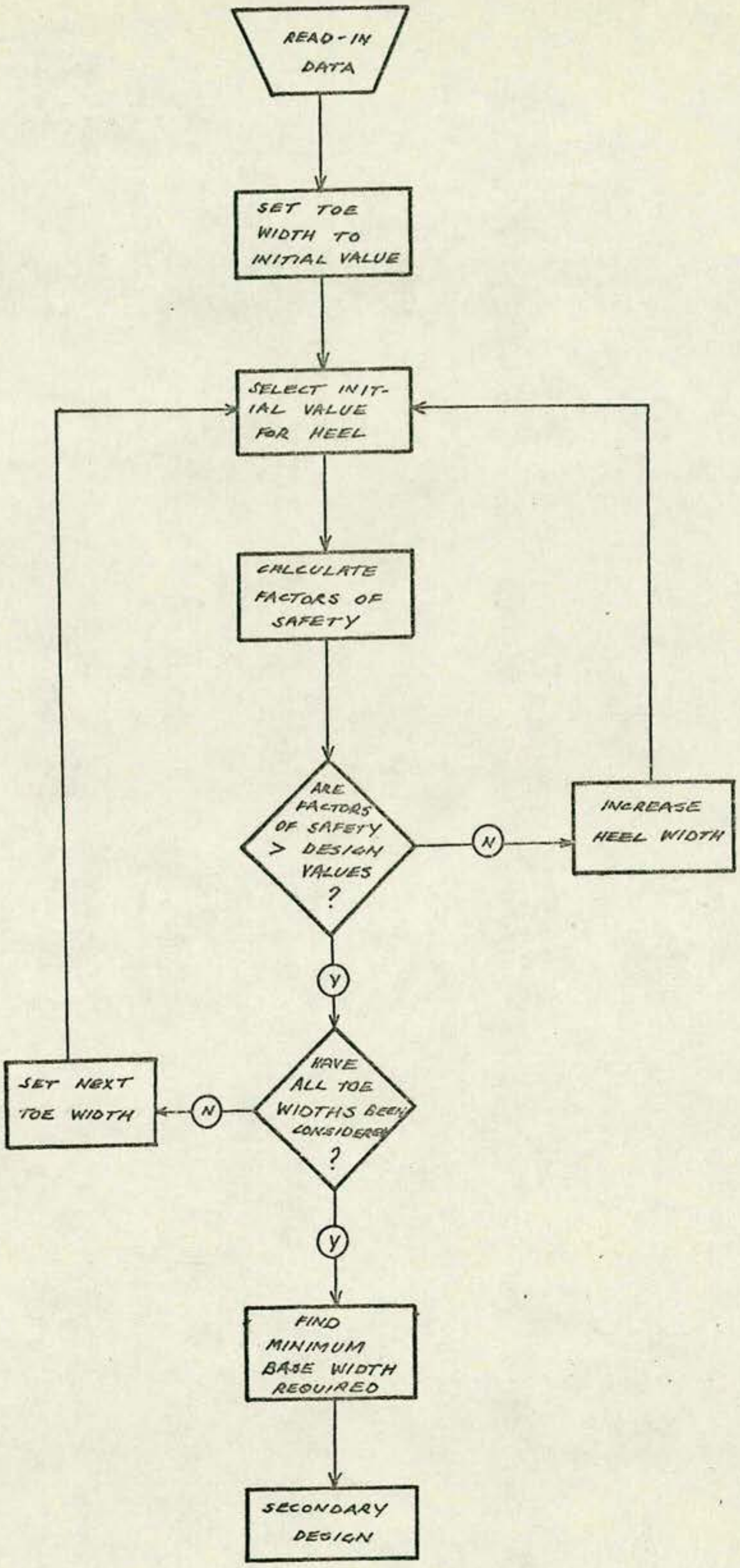


FIG. 4.4. FLOW DIAGRAM FOR AITKENS OPTIMIZATION TECHNIQUE

has been made for use of the Trial Wedge Method irregular backfill surfaces and loads can be included in the design (Knapton, Aitkens, Carsen). The trial wedge method is also available in Wadsworth's program however here the shape of the ground surface is restricted to planar or bi-planar surfaces. When the surface is bi-planar the part furthest from the wall must be horizontal. This restriction is in force presumably so that the point of application of the resultant can be readily found by equation (Terzaghi[28], Taylor[23]). Where the trial wedge analysis method is not available (Purushothaman, Schimming and Fischer) the backfill surfaces must be plane.

There appears to be a tendency to neglect passive pressure forces in front of the wall. Only Knapton and Aitkens consider these forces.

All the programs discussed are for the design of cantilever walls: no programs have been found which will consider gravity wall design. The calculation of the active earth pressures for cantilever walls is always made by considering the pressures on a vertical plane through the heel of the wall. Presumably the same approach would be used for a gravity type of wall.

4.4 AN INTERACTIVE GRAPHICS PROGRAM FOR RETAINING WALL DESIGN

4.4.1 Introduction

The designer will have the following data relating to design:-

(i) height of soil to be retained

(ii) ground profile behind wall

(iii) ground profile in front of wall

(iv) standing water level

(v) soil properties

From this initial data the designer will want to find a suitable wall shape to support the retained soil.

There are essentially two approaches possible with the program. The designer can specify a wall shape and have it analysed by the program. It is unlikely that his first choice of section will prove satisfactory on all counts and the designer can use the interactive facilities to mould this original section into a final design which both satisfies the stability requirements and is an efficient shape. This process can be carried out for both gravity and cantilever walls.

Alternatively where a cantilever wall is to be used the designer can specify certain wall shapes to be analysed by stipulating several toe depths and toe:base ratios. The program will then work through the sections specified and for each one find the width of base necessary to meet the stability requirements. The results from such an analysis can be output in the form of a graph or table.

From inspection of the results the designer may be able to select a final wall shape. However it is more likely that this analysis will serve to indicate the approximate dimensions for an efficient wall shape and that the designer will then want to either re-run the automatic analysis process, this time over a much narrower range of wall heights and toe:base ratios, or to switch to manual analysis.

This summarizes the basic design approach possible with the program. The aim has been to provide a design process that has a certain continuity. The designer can thus change readily from one analysis process to an alternative process, one wall shape to another, one set of soil properties to another. As will be discussed later (section 4.4.7) at any time during this process a record can be made of the current section and results. These can then be studied at a later date.

A simplified flow diagram showing the main parts of the program is shown in Figure 4.5. A description of the overall operation of the program based on this diagram is given in the next few sections. This description is kept general and is intended primarly to show how the program is used for retaining wall design. A more detailed description which is concerned more with the programming aspects of the program is given in chapter 5.

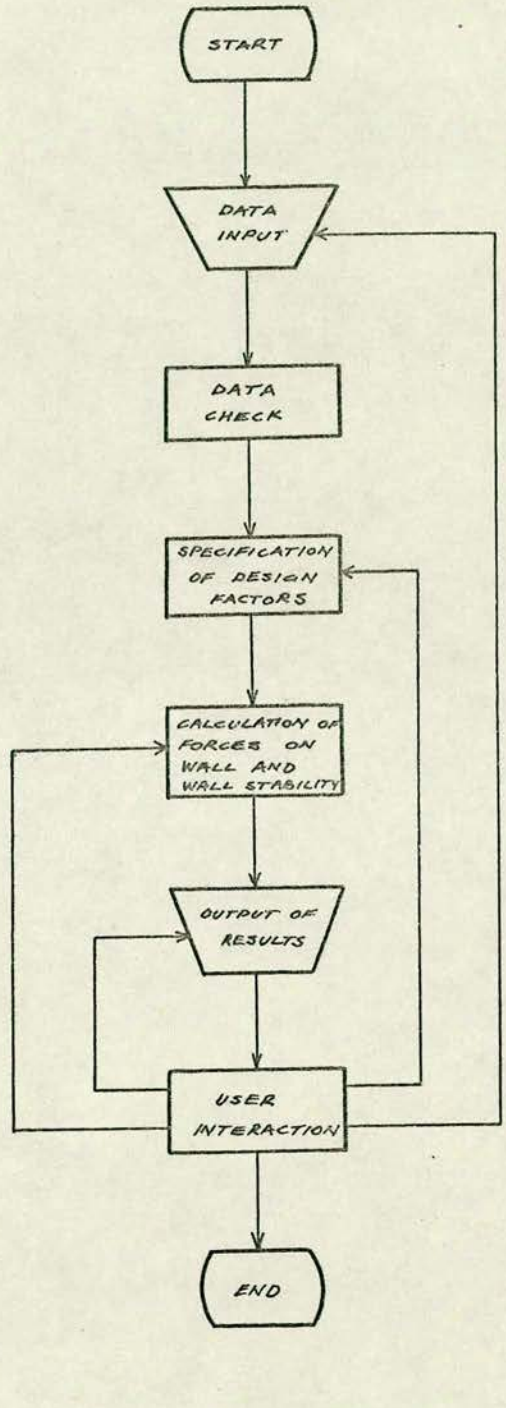


FIG. 4.5. : SIMPLIFIED FLOW DIAGRAM FOR PROGRAM

4.4.2 Data input

4.4.2.1 General

Two forms of data input are available with the program: manual input and input via a data file. The program will output the message:-

DATA INPUT WILL BE :-

1. MANUAL
2. VIA DATA FILE

The user can then use the horizontal cross-hair to select the method required.

4.4.2.2 Data file input

Where several runs of the program are likely with the same or similar initial data the user would be well advised to form a data file containing the initial program data. The layout for such a file is shown in Figure 4.6.

Where input is to be by data file the program will request the file name. This must be no longer than five characters, the first of which must be alphabetic. The file should have the file name extension of .DAT.

Data input by data file has the advantage of course of being very much quicker than manual input.

4.4.2.3 Manual input

The alternative form of data input is manual input via the keyboard in response to prompts from the program. This method is suitable when the data is only made available at the time of running the program. For example where an outside designer comes to use the program for a specific design.

```
8
 36.630  17.000
 36.630  19.000
 39.630  19.000
 40 170  45.000
 41.000  45.000
 41.000  19.000
 50.000  19.000
 50.000  17.000
2
 41.000  45.000
241.000  80.260
115.000 115.000
  0.500   0.400
000.000 000.000
  0.400  0.400
5000.0009000.000
000.000
  6.000  19.000
  0.000   0.000
 00.000
  1.50    2.000
  2.000   1.500   1.000
 26.00
 000.000
150.000
```

FIG 4.6 : DATA FILE LAYOUT

With manual input errors in layout of the data file are avoided although the input process is considerably longer than for input via data file.

Following manual input the program will automatically create a data file from the data if so requested by the user. Where a data file is required the user will be asked to specify a name for the file.

The user can on completion of the manual input correct any errors by using the data check and data change procedures described in the next section.

4.4.3 Data check

During program development errors in data several times led to unexpected results and many times caused the program to 'hang-up'. For this reason it was decided that the provision of a data check process would be advantageous.

The data check facility is optional, so a user re-running a design with already checked data need not waste time.

The user is informed of the check by the message:-

IS DATA CHECK REQUIRED?

The user must reply with either Y or N. The striking of any other characters will simply cause the message to be repeated.

The data check process is two part. First a list of the values of the basic data terms is output. Figure 4.7. If there are any errors in the data then the user should type Y (yes) in response to the message output after the data list, IS DATA CHANGE REQUIRED?

WALL COORDINATES

X	Y
33.80	15.00
33.80	16.50
39.00	16.50
39.00	45.00
41.00	45.00
41.00	16.50
51.80	16.50
51.80	15.00

GROUND COORDINATES

X	Y	SURCHARGE
41.00	45.00	0.00
241.00	80.26	

BACKFILL PROPERTIES

ANGLE OF INTERNAL FRICTION	:	0.59
ANGLE OF WALL FRICTION	:	0.40
DRY DENSITY	:	115.00
SATURATED DENSITY	:	0.00
COHESIVE STRENGTH	:	0.00
ADHESIVE STRENGTH	:	0.00

FRONT CONDITIONS

X-COORD	:	6.00
Y-COORD	:	19.00
SLOPE	:	0.00
SURCHARGE	:	0.00

FOUNDATION PROPERTIES

ANGLE OF INTERNAL FRICTION	:	0.40
ANGLE OF WALL FRICTION	:	0.40
BASE ADHESION	:	0.00
BEARING CAPACITY	:	5000.00
BEARING MAXIMUM		0.00

DATE : 15-OCT-73	BASIC DATA	TRIAL NO. :

FIG. 4.7 : DATA CHECK OUTPUT

The data change routine will then be called up and a list of basic data terms will be output along with the cross-hairs. Figure 4.8. To change any term in the list the user simply aligns the horizontal cross-hair with the term to be changed and strikes any teletype key. The current value of the term selected will then be output and the program will wait for the user to input the new value for the term.

Once the required amendments have been made the horizontal cross-hair is positioned on the amendments complete line and again any teletype character struck.

4.4.4 User specification of design factors

4.4.4.1 Program units

The program will run for both metric and imperial units but must be informed which are to be used.

The program outputs the message:-

SPECIFY UNITS : METRIC OR IMPERIAL?

The user should reply with M or I.

4.4.4.2 Soil above toe

When considering cantilever walls or gravity walls with a toe projection the passive earth pressure is calculated on a vertical plane passing through the toe of the wall. The earth between this surface and the front of the wall can be considered as a stabilizing force. However some designers do not include passive earth pressure in the stability analysis because of possible disruptive influences in front of the wall (chapter 3, section 3.4.2.).

```
***BASIC DATA CHANGE***
.
BACKFILL    : DRY DENSITY        :     115.00    100.00
            : SUBMERGED DENSITY  :
            : SOIL FRICTION      :
            : WALL FRICTION      :
            : COHESION           :
            : ADHESION           :
FOUNDATION  : BEARING CAPACITY   :    5000.00   6000.00
            : BEARING MAXIMUM    :
            : SOIL FRICTION      :
            : BASE FRICTION      :
            : COHESION           :
AUTOMATIC   : STEM THICKNESS     :
            : BASE THICKNESS     :
            : RETAINED HEIGHT    :
            : DESIGN FSTIP       :
            : DESIGN FSLID       :
            : DESIGN FSBCY       :
FRONT SOIL  : X-COORDINATE       :
            : Y-COORDINATE       :      23.00     20.00
            : ANGLE OF SLOPE     :
.
.
.
.
AMENDMENTS COMPLETE
```

FIG. 4.8. : TYPICAL DATA CHANGE OUTPUT

The soil weight above the toe is also open to such influences and it is therefore left to the designer to decide whether or not its effect should be included in stability calculations.

The program outputs the message:-

SOIL WEIGHT ABOVE TOE TO BE INCLUDED IN STABILITY?

The user should reply with Y or N.

4.4.4.3 Percentage of passive pressure

The computer outputs the message:-

WHAT % OF PASSIVE PRESSURE CAN BE USED?

The user should reply with a value between 0 and 100. A value outside this range is unacceptable and will cause the message to be repeated.

4.4.4.4 Water in tension crack

When considering a cohesive soil behind the wall the trial wedge analysis method makes allowance for development of a tension crack at the surface of the soil. Two tension cracks will develop as shown in Figure 4.9. Two conditions should be considered. If there is drainage system down the back of the wall no water will collect in any tension crack behind the wall back. Water will of course lie in the crack remote from the wall back and the effect of this water should be included in the analysis of forces acting on the failure wedge.

Where no provision for drainage has been made water will collect in a tension crack behind the wall back. The water pressures in each tension crack will cancel each

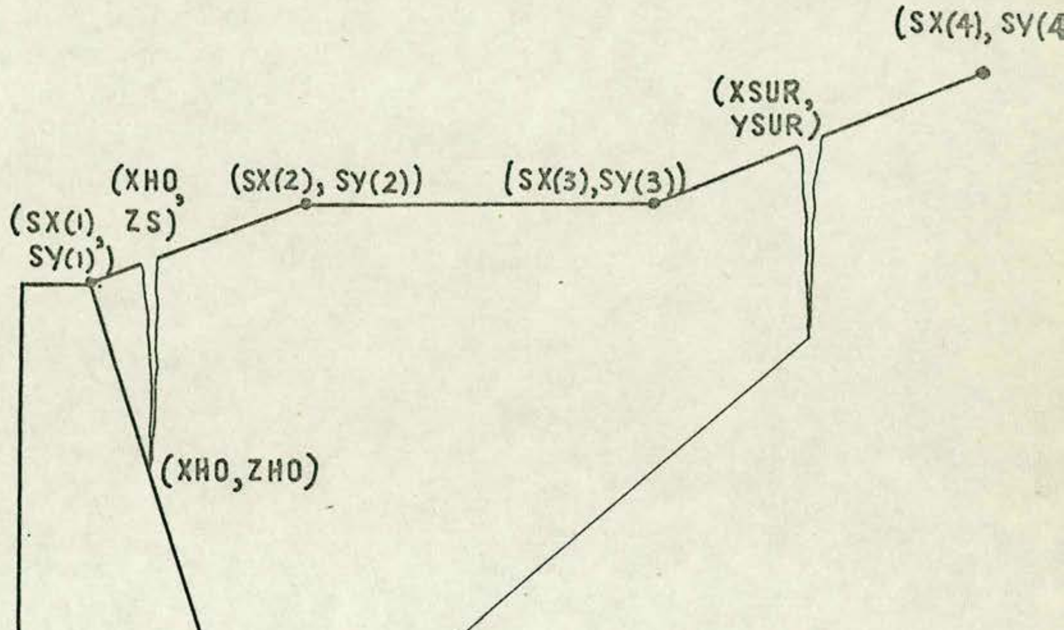


FIG. 4.9. : DEVELOPMENT OF TENSION CRACKS BEHIND WALL

other out when the forces on the failure wedge are considered. However the direct effect of the water pressure on the wall back should be included in the stability analysis of the wall.

The user should inform the program of which case will be relevant in any wall design. The program will output the message:-

IS THERE EFFECTIVE DRAINAGE BEHIND WALL BACK?

The user should reply with Y or N.

4.4.4.5 <u>Provision of wall key</u>

The program will output the message:-

DO YOU WANT A WALL KEY?

The user should reply with Y or N. When a wall key is required the program will then ask for the key width and depth to be specified.

4.4.5 <u>Selection of analysis method for cantilever wall design</u>

Whether or not the original wall shape to be analysed is a cantilever type or gravity wall with tri-planar wall back the user must specify the analysis method to be used, should walls of this shape be encountered. The program will output the message:-

METHOD FOR CANTILEVER WALL ANALYSIS:-

1. INCLUDED WEDGE

2. SIMPLE

The user can then use the horizontal cross-hair to select the analysis method required. As described in chapter 3, section 3.1.3.4, the included wedge method considers outer failure surfaces that develop between the heel and the wall back, while the simple analysis process considers active earth pressures on a vertical plane through the heel of the wall.

Having specified which analysis method is to be used for walls whose backs comprise of three planes the program will ask the user whether manual or automatic analysis is required for cantilever walls.

IS AUTOMATIC CANTILEVER DESIGN REQUIRED?

When the answer is Y(es) the user will then have to input the details relating to the scope of the automatic analysis required. The input is in reply to program prompts and is self-explanatory. Figure 4.10.

4.4.6 Calculation of forces on wall and wall stability analysis

The analysis procedures used in the program for the calculation of active and passive earth pressures at the wall have been described in chapter 2. The methods of assessing wall stability were described in chapter 3.

A breakdown of the programming for the wall analysis is given in chapter 5.

```
**AUTOMATIC CANTILEVER ANALYSIS**
HOW MANY TOE DEPTHS ? :5
TOE DEPTH INCREMENT :1.
INITIAL TOE DEPTH VALUE :2.
INITIAL BASE WIDTH :10.00
BASE INCREMENT :2.00
NUMBER OF RATIOS TO BE CONSIDERED :4
RATIOS(1) :.2
RATIOS(2) :.4
RATIOS(3) :.6
RATIOS(4) :.8
```

FIG. 4.10. : DATA INPUT FOR AUTOMATIC DESIGN

4.4.7 Output of results

4.4.7.1 Manual analysis

Where manual analysis has been used for either a cantilever or gravity wall the results of the stability analysis will be as shown in Figure 4.11.

The following facts should be noted about the values of the factors of safety:-

(i) If the resultant force causing the wall to slide forward is negative (Figure 4.12) the factor of safety against sliding is automatically set to 99.00.

(ii) If the resultant overturning moment about the toe is negative (again Figure 4.12) the factor of safety against overturning is set equal to 99.00.

(iii) If the resultant force on the base lies outside the base width of the wall the factor of safety against bearing failure is set equal to zero. This condition will also be shown by the arrow which indicates the position of the resultant on the base. Figure 4.13.

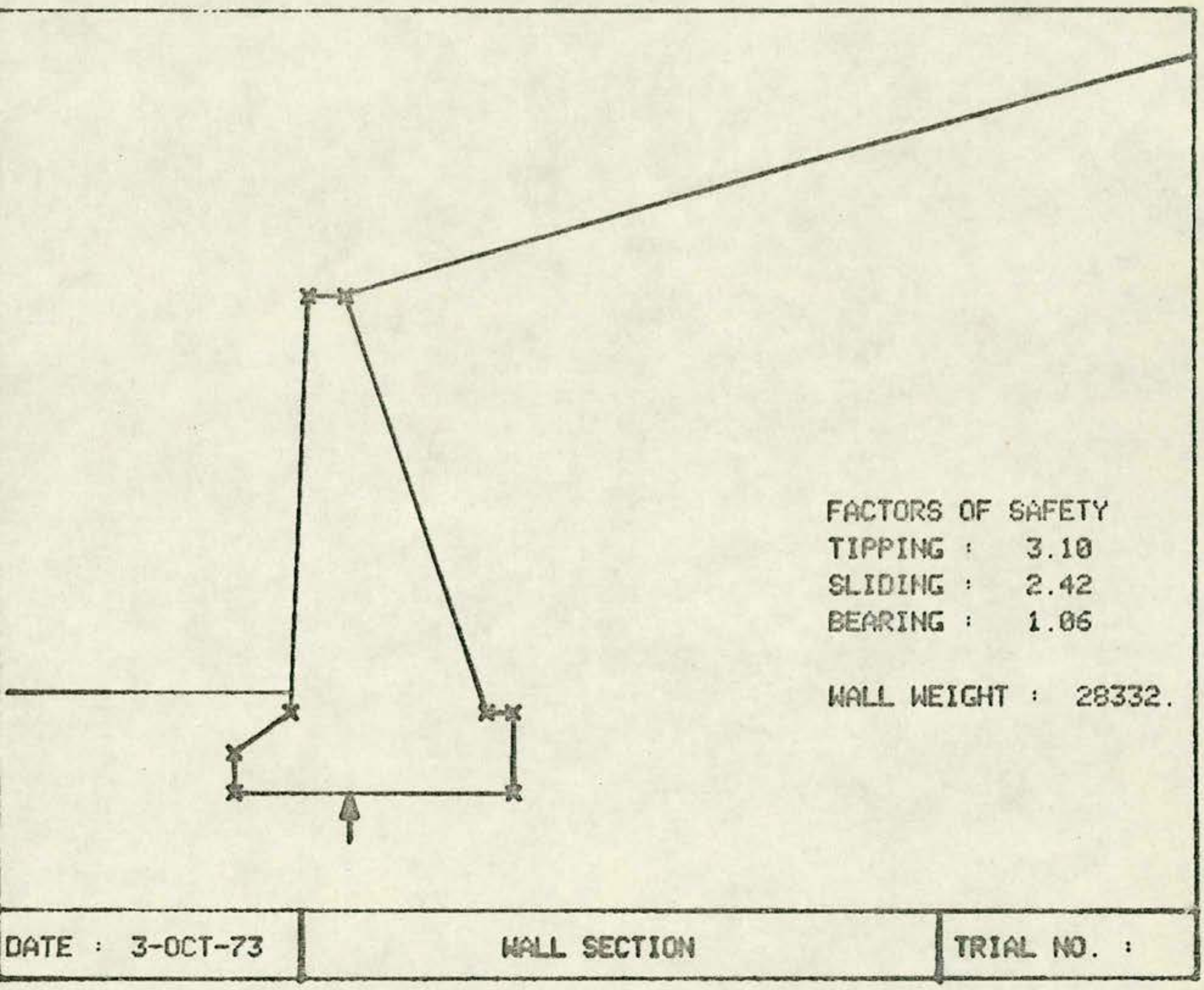


FIG. 4.11.: RESULTS FOR TYPICAL MANUAL ANALYSIS

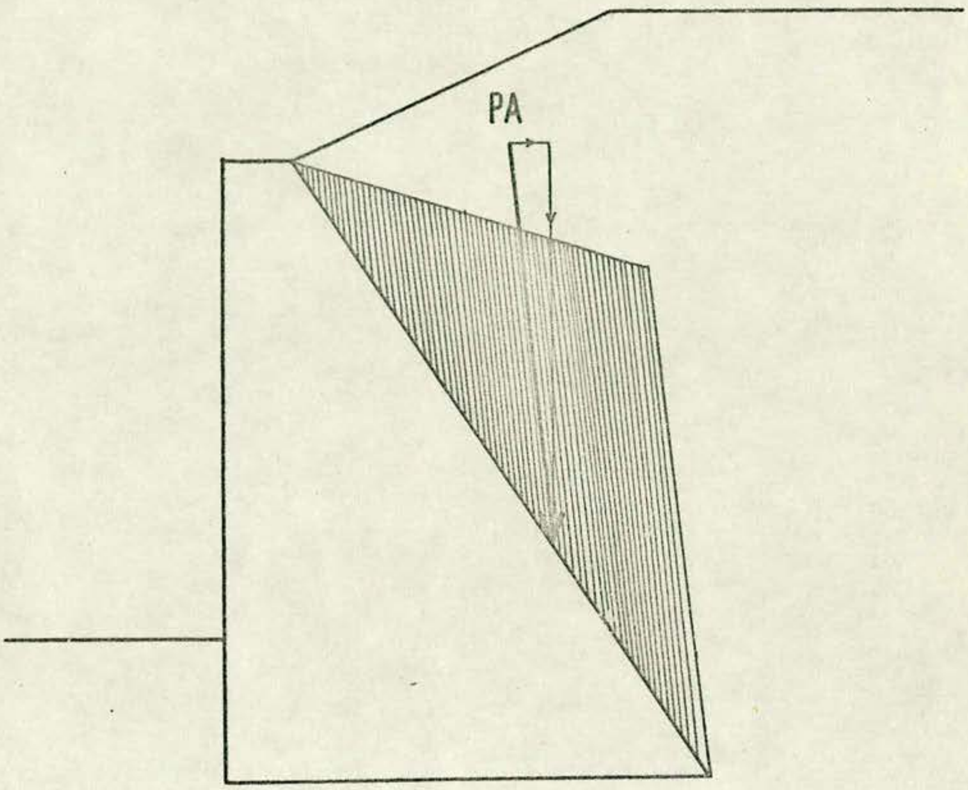


FIG. 4.12. : CONDITIONS FOR NEGATIVE OVERTURNING MOMENT

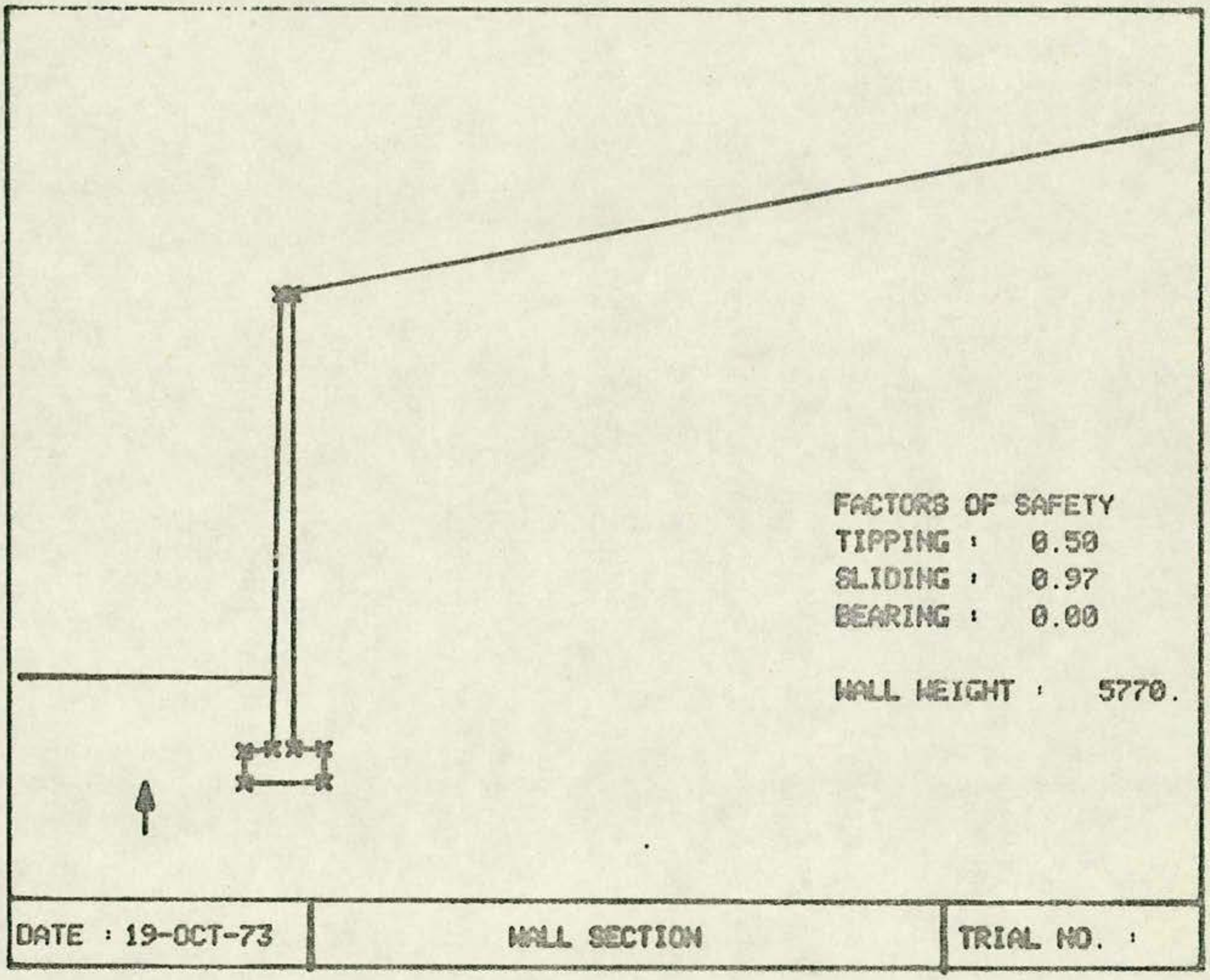


FIG. 4.13.: RESULTANT LIES OUTSIDE WALL BASE

4.4.7.2 Automatic cantilever design

Where the automatic design procedure has been used for cantilever walls the results of the analysis are not output directly. On completion of the designs the program outputs a menu of the alternative courses of action open to the designer. Figure 4.14. The results from the automatic analysis can be output in three ways:-

(i) Graph of base against toe depth

When the automatic analysis process has been carried out for several toe depths it is useful to have a graph of base against toe depth. If more than one toe:base ratio was considered at each toe depth then the lowest base value found for the various ratios is used for the graph. Figure 4.15.

This is probably the most useful result from the automatic analysis because it will let the designer know right away what variation in base width can be expected from founding the wall at greater depth.

(ii) Graph of base against ratio

Where more than one toe:base ratio has been considered in the automatic analysis the designer may prefer to preserve the results for each toe depth and output a graph of base width against ratio for each toe depth.

AUTOMATIC CANTILEVER ANALYSIS

.
.
1 GRAPH OF BASE AGAINST TOE DEPTH
2 GRAPH OF BASE AGAINST RATIO
3 TABLE OF RESULTS
4 DRAWING OF SECTION
5 BASE KEY
6 RE-RUN PROGRAM
7 RE-RUN AUTOMATIC ANALYSIS
8 CHANGE TO MANUAL ANALYSIS
9 BASIC DATA CHANGE
10 EXIT

FIG. 4.14.: MENU FOR USER INTERACTION AFTER AUTOMATIC DESIGN

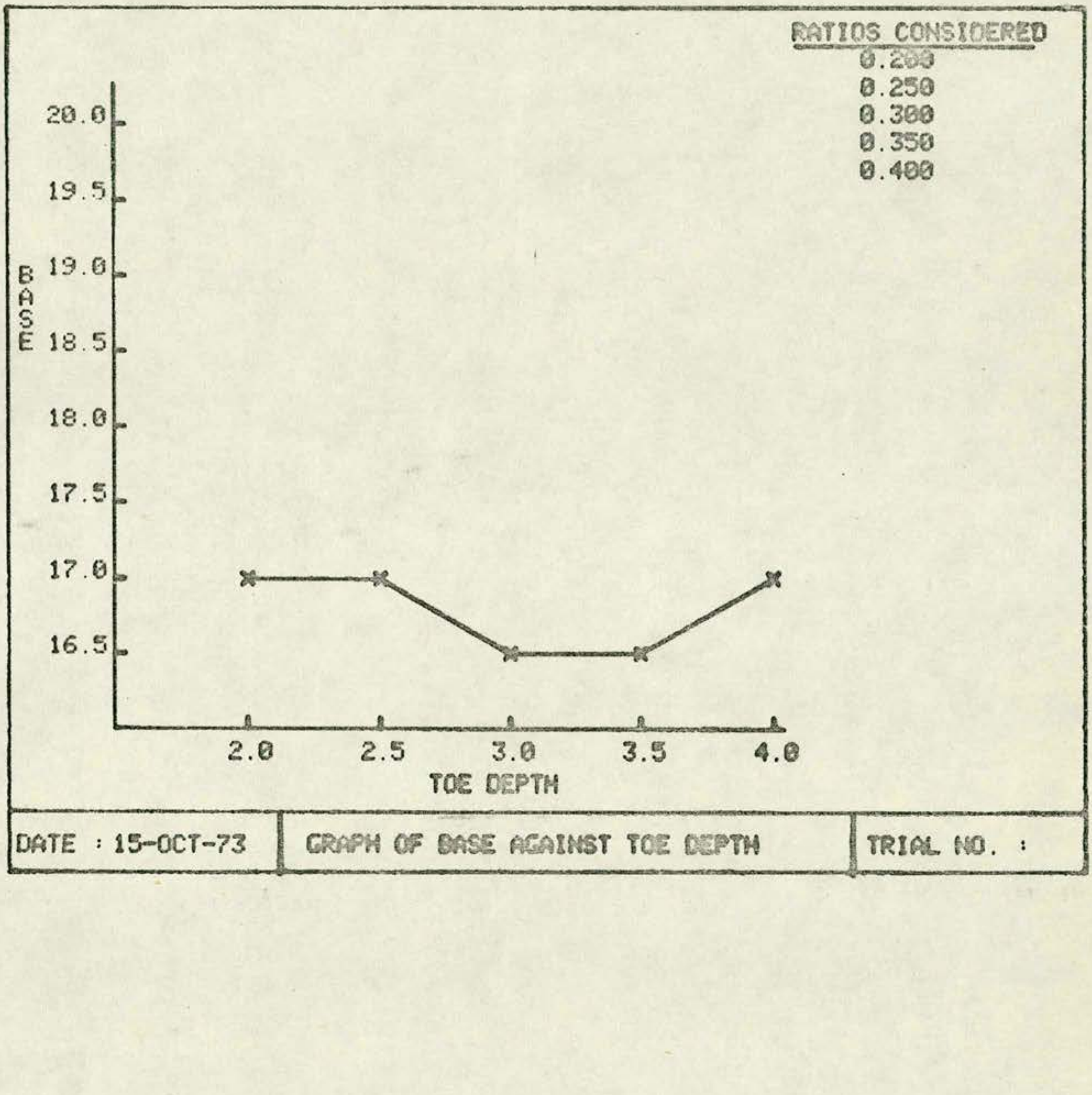


FIG. 4.15. : GRAPH OF BASE AGAINST TOE DEPTH FROM AUTOMATIC RESULTS

On some occasions conditions may make it impossible to vary the toe-depth i.e. bedrock close to ground surface, presence of utility services etc. For such a case an analysis of several different toe:base ratios at a constant toe depth will be required.

Two different sizes of graph of base against ratio can be output. When only one toe depth was specified the graph will occupy the full screen
However where more than one toe depth was analysed the graphs will be scaled down to occupy one quarter of the screen area and will be output at a maximum of four at a time. Figure 4.16.

(iii) Table of results

As an alternative to graphical output, the results can also be presented in tabular form. Figure 4.17.

4.4.8 User interaction: Manual analysis

4.4.8.1 General

Where manual analysis has been used the results are output on the screen together with a drawing of the cross-section (Figure 4.11). The program then enters interactive mode and the cross-hairs are displayed on the screen.

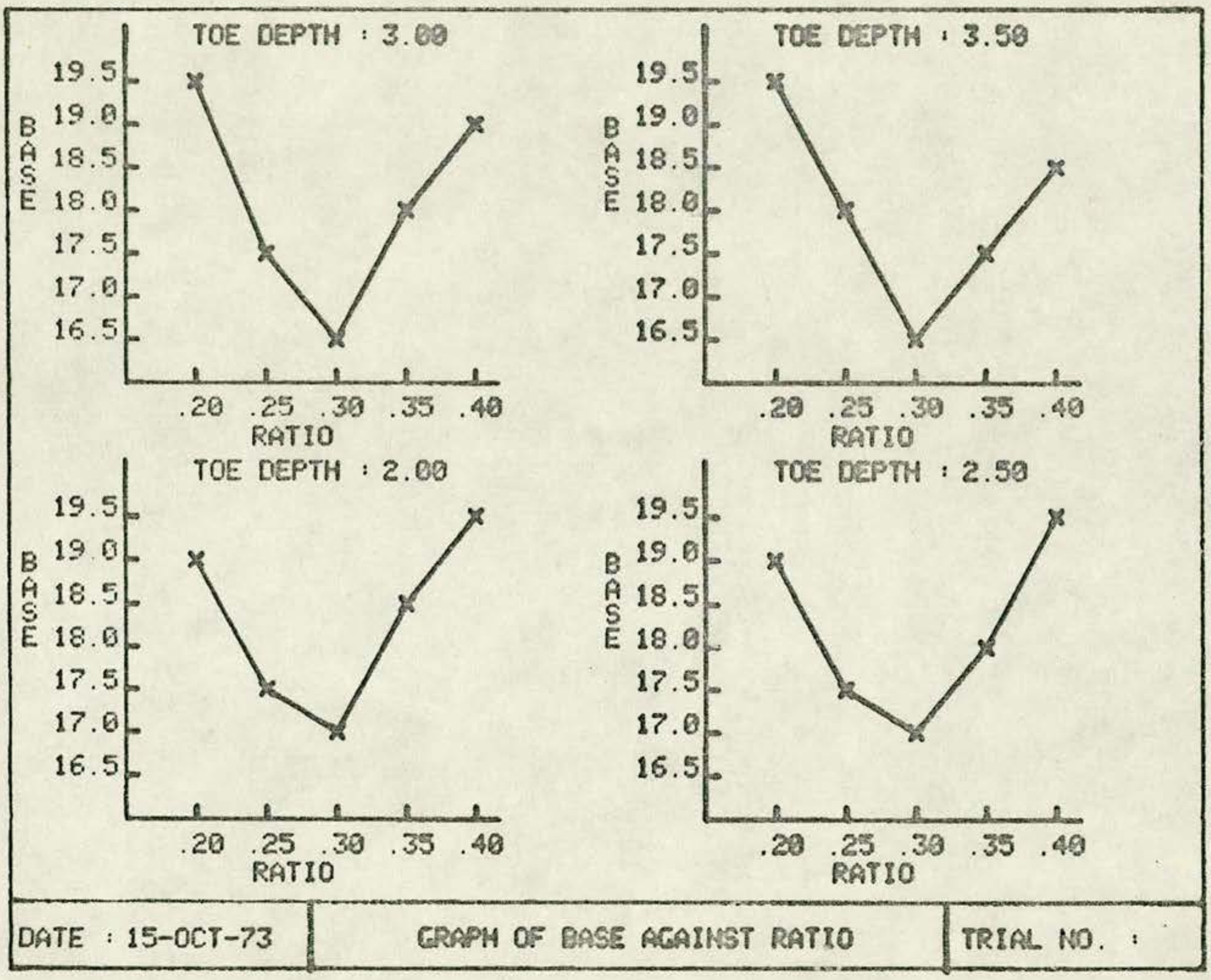


FIG. 4.16. : GRAPHS OF BASE AGAINST RATIO FROM AUTOMATIC RESULTS

TOE DEPTH	RATIO	BASE	WALL HEIGHT
2.00	0.20	19.00	12225.00
2.00	0.25	17.50	11687.50
2.00	0.30	17.00	11775.00
2.00	0.35	18.50	12112.50
2.00	0.40	19.50	12337.50
2.50	0.20	19.00	12375.00
2.50	0.25	17.50	12037.50
2.50	0.30	17.00	11925.00
2.50	0.35	18.00	12150.00
2.50	0.40	19.50	12487.50
3.00	0.20	19.50	12637.50
3.00	0.25	17.50	12187.50
3.00	0.30	16.50	11962.50
3.00	0.35	18.00	12300.00
3.00	0.40	19.00	12525.00
3.50	0.20	19.50	12787.50
3.50	0.25	18.00	12450.00
3.50	0.30	16.50	12112.50
3.50	0.35	17.50	12337.50
3.50	0.40	18.50	12562.50
4.00	0.20	19.50	12937.50
4.00	0.25	18.00	12600.00
4.00	0.30	17.00	12375.00
4.00	0.35	17.00	12375.00
4.00	0.40	18.00	12600.00

DATE : 15-OCT-73	AUTOMATIC ANALYSIS : TABLE OF RESULTS	TRIAL NO. :

FIG. 4.17. : TABLE OF TYPICAL AUTOMATIC DESIGN RESULTS

The user may now use the cursor to modify the shape of the wall section or the ground profile, or type certain command characters which will cause the program to carry out a variety of operations. These alternatives are now considered in more detail.

4.4.8.2 Graphical amendments

To move a wall or ground co-ordinate the user must position the cross-hairs on the point to be moved (or within 5 mm of it) and type M (MOVE). This will enable the point to be moved to be identified by the program. The cross-hairs are then moved to the position at which the point is to be resited. The new position can then be fixed by typing M (MARK). A dot will then appear on the screen indicating the new position of the point. This process may be repeated for as many points as are required.

Because the display on the screen is not a refreshed display selective deletion and updating of points of the display file is not possible. In other words during the amendment of the section the amended points can only be redrawn by completely erasing the screen and redrawing from scratch.

This process takes time and it is left to the user to decide when a redraw is required. A redraw is achieved simply by typing R (REDRAW) and can be done at any time during the interaction stage.

The method by which the movement of the co-ordinates is achieved will now be outlined. In forming the display file for the section display each wall co-ordinate is marked with a cross and each surface co-ordinate by a dot. Each cross and dot form individual segments of the display file. The wall crosses are stored in segments with the user name 1, 2, 3, etc. All ground profile dots are in segments with user label 101, 102, etc.

All the crosses and dots are sensitive to cursor identification. There is a Sturgeon routine that will find which sensitive segment lies closest to the current position of the cross-hairs provided there is such a segment within about 5 mm of the cross-hairs.

To move a point therefore the cursor is positioned on or near the point and M (MOVE) typed. The position of the cursor will then be calculated and the program will look for the sensitive segment nearest to the current position.

If a sensitive segment is found the cross-hairs are moved on to the point. If no segment is found they simply remain where they are and the user will have to repeat the identification procedure this time positioning the cross-hairs more accurately.

When a segment is located its system name will be known to the program and from this its user name can be found. From the user name the program will be able to establish whether it is a wall co-ordinate or surface co-ordinate that is to be moved and exactly which one has been selected.

After the second typing of M, to mark the position at which the point is to be resited, the program will calculate the co-ordinates of the current position of the cursor and use these co-ordinates to redefine the position of the point moved.

4.4.8.3 Controlled change of ordinate

Sometimes it will be preferable to have a controlled change of wall or ground surface co-ordinate as opposed to changing it with the cross-hairs i.e. when it is necessary to specify a co-ordinate exactly.

This can be achieved by placing the cross-hairs on the point to be changed and typing O (ORDINATE CHANGE). The current x- and y-co-ordinates of the point will then be output on the screen and the user can input the new values.

4.4.8.4 Change of surcharge loading

Before details are given of how the surcharge on the backfill can be changed it is worth considering how surcharges are defined in the program.

Any surcharge on the backfill surface must be defined as lying between two of the points defining the backfill surface.

For example where the backfill surface is plane only two points are required to define it. Figure 4.18a. For this ground profile

SX(1) = 50 SY(1) = 40 SURCH(1) = 0

SX(2) = 150 SY(2) = 40

If the complete surface of the backfill is to be surcharged no additional points need be defined, SURCH(1) is simply given the surcharge value. Figure 4.18b.

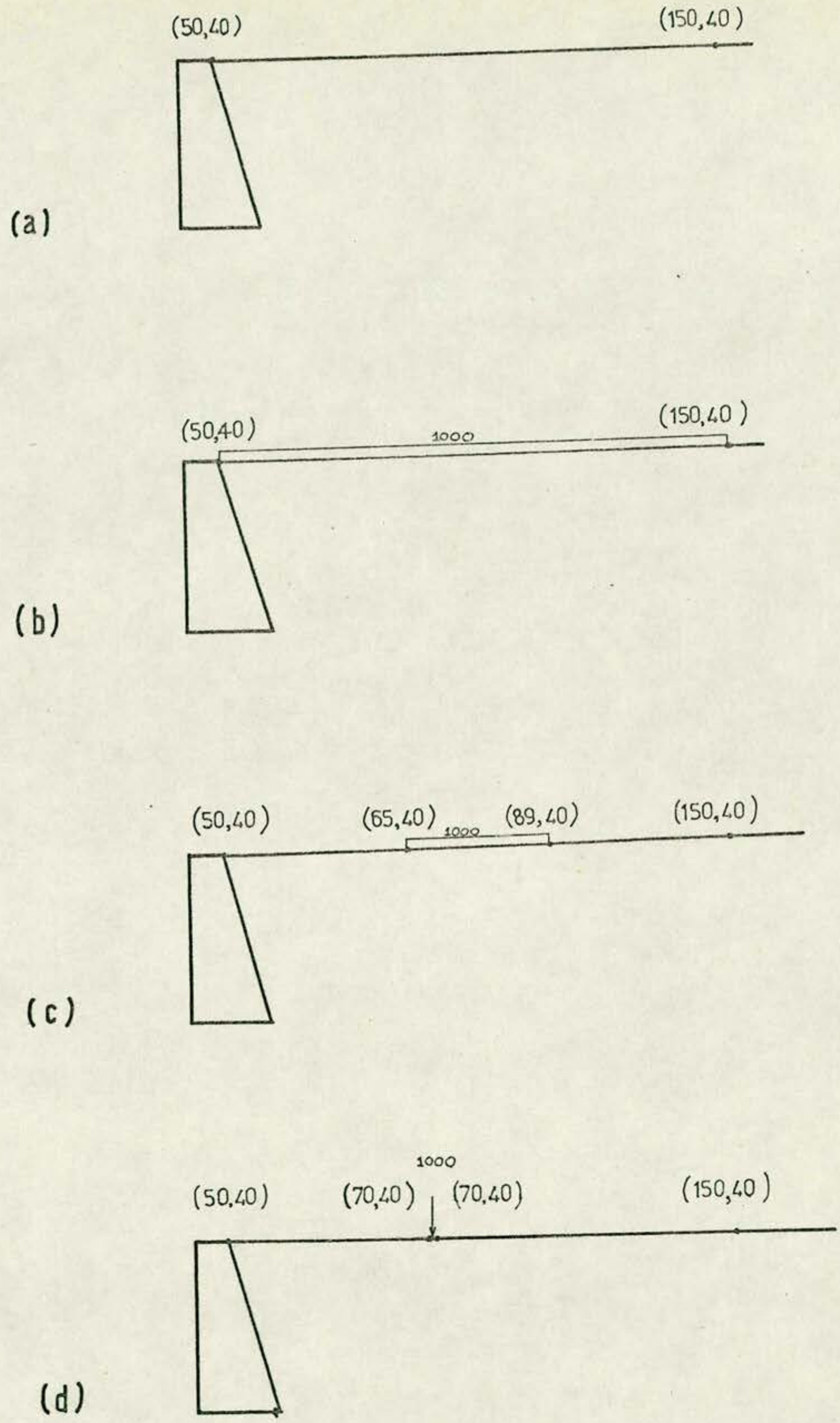


FIG. 4.18. : METHOD FOR DEFINITION OF SURCHARGE LOADS

However if only part of the backfill is to be loaded, for example by construction of a road, two additional surface co-ordinates will have to be defined to enable the surcharge to be dealt with (Figure 4.18c). The data now required is

SX(1) = 50	SY(1) = 40	SURCH(1) = 0
SX(2) = 65	SY(2) = 40	SURCH(2) = 1000
SX(3) = 89	SY(3) = 40	SURCH(3) = 0
SX(4) = 150	SY(4) = 40	

Line loads are defined in the same way as surcharges, i.e. as lying between two surface points, however when the load is a line load the co-ordinates of the two surface points are identical (Figure 4.18d).

To change any existing surcharge or to introduce a new surcharge the cursor is positioned at the surface co-ordinate at which the surcharge loading is to start. If S (SURCHARGE) is then typed the current surcharge loading on this section of the backfill is output on the screen and the user can then input the new value required.

When the load to be altered is a line load this procedure is as for a uniformly distributed load except that the load to be changed is identified by typing L (LINE LOAD) instead of S (SURCHARGE).

4.4.8.5 Data change

There are several reasons why the designer may wish to change the basic data of the program. These are:-

(i) It may be impossible to achieve the required factors of safety with the original soil properties. An alternative backfill material must be tried.

(ii) A satisfactory design has been found. However the designer wishes to see how sensitive the design is to a small change in the soil properties.

(iii) There is a choice of backfill materials and more than one is to be considered to find which gives the most economical wall section.

By typing C (CHANGE DATA) when the program is in interactive mode the list of basic data terms will be output on the screen (Figure 4.8). The value of any term in the list will be output if the horizontal cross-hair is set level with the term and any teletype key is struck. The program will now await input of a new value for the term. If it is decided to leave the value unchanged the current value must be re-input. Typing only carriage return will set the term to zero.

Once all data amendments have been completed the horizontal cross-hair is positioned on the amendments complete line and any character struck on the teletype. The program will then return to basic interactive mode.

The data change described above is achieved using the Sturgeon(22) menu selection routines together with an array called BASIC( ) in which all the basic data terms are contained. The storage of the data terms in an array considerably facilitates the data changing process although it is necessary after completion of the amendments to up-date the original data terms from the data array. This procedure is discussed in more detail in chapter 5, section 5.3.12.

4.4.8.6 <u>Output of co-ordinates and soil properties</u>

With the program in interactive mode the user can obtain an output of the current wall and backfill co-ordinates together with a list of the soil properties by typing W (WRITE). A typical output is shown in Figure 4.7.

A list of this nature will be useful as a record of what type of soil was used in the analysis. The list of wall and backfill co-ordinates will be necessary to supplement a drawing of the section.

4.4.8.7 <u>Provision of user assistance</u>

The user interaction process relies considerably upon keyboard commands. These were used in preference to menu selection techniques because when there are a lot of users on the timesharing system the output of a menu can take some time. It can become very frustrating waiting for the menu to be output. The use of single letter commands is a much more rapid process although it may prove awkward for a user unfamiliar with the commands. If the user requires assistance with the commands by typing H (HELP) a list of commands and their functions will be displayed on the screen. Figure 4.19.

```
.
.
**USER CONTROL COMMANDS**
.
A : ANALYSE SECTION
B : BORDER FOR DISPLAY
C : CHANGE DATA
D : DRAW SECTION
E : ERASE CROSS-HAIRS TEMPORARILY
F : FORCE DETAILS
G : GO TO START OF ANALYSIS
H : HELP - LIST OF USER COMMANDS
K : KEY FOR BASE
L : LINE LOAD ADJUSTMENT
M : MOVE ANOTHER POINT NO REDRAW
O : COORDINATE CHANGE VIA KEYBOARD
R : RE-RUN PROGRAM
S : SURCHARGE CHANGE
W : WRITE OUT WALL COORDINATES
X : EXIT FROM PROGRAM
```

FIG. 4.19. : OUTPUT FROM H(HELP) COMMAND

4.4.8.8 Provision of base key

This is the second stage during the running of the program that the user can introduce a base key into the wall design. As discussed in chapter 3, section 3.4.4, the key is automatically placed at the heel of the wall.

If the user has difficulty in providing the required stability against sliding failure a key can be introduced or an existing key amended by typing K (KEY).

The program will then request values for the width and depth of the key. Following input of these terms an automatic re-draw is carried out and the program returns to user interactive mode.

4.4.8.9 Output of force details

A list of the resultant earth forces and water forces acting on the wall will be output in response to the command F (FORCES).

The magnitude, line of action and point of application of each force is given (Figure 4.20).

4.4.8.10 Provision of boundary for display

For displays that are to be saved as hard copies the presentation of the hard copy can be enhanced by surrounding it with a boundary.

By using command B(BOUNDARY) any display on the screen will be automatically provided with the surround shown in Figure 4.21. The date is automatically inserted in the left hand bottom corner of the surround.

FORCE	MAGNITUDE	ANGLE	X	Y
ACTIVE TOP	25581.	0.87	47.96	25.87
ACTIVE BOTTOM	0.	0.00	0.00	15.00
ACTIVE BASE	0.	0.00	0.00	15.00
PASSIVE	10473.	0.00	36.00	32.67
WATER TOP	0.	0.00	0.00	15.00
WATER BOTTOM	0.	0.00	0.00	15.00
WATER BASE	13281.	1.22	49.49	21.67

DATE : 15-SEP-73	FORCE DETAILS	TRIAL NO. :

FIG. 4.20: OUTPUT OF DETAILS OF FORCES ON WALL

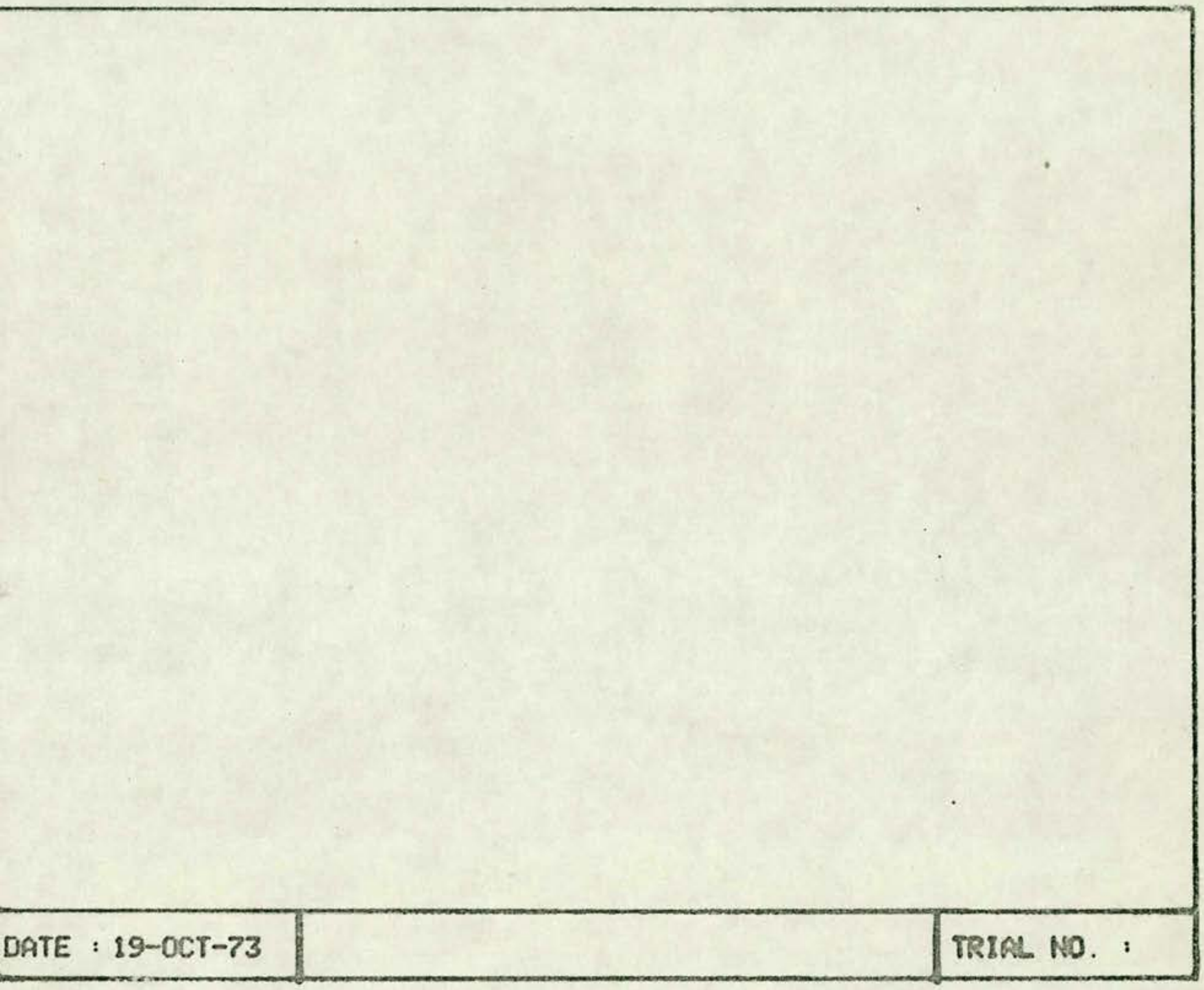


FIG. 4.21. : DISPLAY BOUNDARY

The user is left to provide a heading for the display (in the centre of the bottom of the surround) and to allocate a trial number.

This is done by the following procedure:-

(1) erase cross-hairs temporarly by typing E

(2) switch terminal to local mode

(3) use linefeed and space-bar keys to position the cursor

(4) input desired heading

(5) return terminal to line mode

(6) restore cross-hairs by typing carriage return

4.4.8.11 <u>Re-running commands</u>

Three commands are available for re-running the program:-

(i) <u>A-command</u>

If after making some alteration to the design, backfill surface or soil properties the user wishes to re-analyse the section this can be achieved by typing A (ANALYSE). On completion of the analysis the program will output the results as before.

(ii) <u>G-command</u>

When the designer wishes to change the analysis method this can be achieved by typing G (GO). The program will then return to the stage at which the user must specify the design factors and select the analysis method.

(iii) R-command

If it is required to start the program again from scratch the user should type R (RE-RUN). This will cause the program to return to the data input stage. This command would be used if the designer wants to read-in a new data file and avoids the necessity of exiting from the program and re-loading.

4.4.8.12 Exit from program

While it is possible to exit from the program at any stage during the running by typing CONTROL C twice this is a system command and may result in a loss of echo. The program command to exit from the program is X (EXIT). This command simply causes the program to go to the END statement.

4.4.9 User Interaction : Automatic Analysis

4.4.9.1 General

User interaction following the completion of an automatic cantilever wall design is accomplished by menu selection. The various alternatives available to the user are shown in Figure 4.22 .

The output of the results in the form of a graph or table has already been discussed in section 4.4.7.2.

The provision of the base key, basic data change, re-run program and exit options are all similar to the K(KEY), C (CHANGE DATA), R (RE-RUN) and X (EXIT) options

AUTOMATIC CANTILEVER ANALYSIS

```
1   GRAPH OF BASE AGAINST TOE DEPTH
2   GRAPH OF BASE AGAINST RATIO
3   TABLE OF RESULTS
4   DRAWING OF SECTION
5   BASE KEY
6   RE-RUN PROGRAM
7   RE-RUN AUTOMATIC ANALYSIS
8   CHANGE TO MANUAL ANALYSIS
9   BASIC DATA CHANGE
10  EXIT
```

FIG. 4.22.: MENU FOR USER INTERACTION AUTOMATIC DESIGN

for user interaction following manual analysis. The other options available differ from those available with manual analysis and will now be discussed.

4.4.9.2 Drawing of section

Having completed an automatic design the user may want to make a copy of the ground shape under which the analysis was carried out. By opting for a drawing of the section the most recent wall shape analysed will be output along with ground surface profile.

4.4.9.3 Re-run automatic analysis

If the user wishes to re-run the automatic analysis procedure by selecting this option from the menu he will be returned to stage at which the program requests data for the automatic analysis.

4.4.9.4 Change to manual analysis

When this option is selected the program will switch directly to the manual interaction stage and a drawing of the current wall section and backfill profile will be output on the screen.

4.4.10 Exit from program

The user can exit from the program at any stage during the run by simply typing CTRL C twice.

The more conventional exiting procedure is however to type X when at the manual interaction stage or select the EXIT option when at the automatic interaction stage.

4.5 SUMMARY

The basic aim of the program is to speed up the primary stage of the design of a retaining wall by relieving the designer of lengthy calculations. The advantages offered by this process would be rather be-littled if use of the program entailed restrictions on the shapes of wall profile, soil properties and backfill surface. The program has therefore been written to be as general as possible and every attempt has been made to avoid unnecessary restrictions.

The design procedure has been kept 'fluid' and a high degree of user interaction is made available. It is hoped that this will permit the designer to make full use of his skill and experience in arriving at a suitable wall shape.

CHAPTER 5

DETAILED PROGRAM DESCRIPTION

5.1 INTRODUCTION

In chapter 4 section 4 an outline of how to use the program was given. This description was intended primarily to acquaint users with the procedure for running the program. No attempt was made to discuss the programming behind the various operations.

In this chapter a more detailed description is given both of the main program and the subroutines. This description will be of interest primarily to those involved in the future development of the program. Throughout the description headings have been chosen to correspond to those used in the program itself. This permits direct cross-reference between the description in this chapter and the program (Appendix III).

5.2 MAIN PROGRAM

5.2.1 Set Initial Values

5.2.1.1 Set logical variables

Throughout the program logical variables are used to keep track of which processes have been carried out, which of two options the user has selected etc. Certain of these variables require setting at the start of the program. It should be pointed out that the terms LOG and LOGF are used simply as alternatives for .TRUE. and .FALSE. This was necessary under certain conditions because of a system bug which meant that the terms .TRUE. and .FALSE. were not recognised.

5.2.1.2 Set constant terms

The basic degrees (45°, 90°, 180°) are set to standardise the procedure when using these angles in equations.

The terms which govern incremental procedures in the program are set at this point. NLIM1 is the number of elements into which the top part of a wall, with a non-planar back, is considered in the numeric differentiation process to find the point of application of the resultant earth pressure. NLIM2 is the total number of elements for both plane and bi-planar backs. WEDGNO and NOWEDG refer to the number of included soil wedges that are analysed in the included wedge method.

All these terms can be varied if necessary, but this cannot be done by the normal user interaction procedure. The values have to be changed by actually editing the program. For example if a very accurate analysis was required the values could all be increased to give smaller increments in the analysis process. This however will seldom be necessary and it was therefore not considered that these terms should be made available for change through the normal user interaction procedure.

5.2.2 Data Input

Figure 5.1: TYPICAL LAYOUT OF DATA FILE

TERM	PROGRAM NAME	FORMAT	EXAMPLE
Number of wall co-ordinates	NC	I2	4
X-co-ordinates, Y-co-ordinates	WX(I) WY(I)	2F8.3 2F8.3 2F8.3 2F8.3	35.000 20.000 40.000 30.000 42.000 30.000 42.000 20.000
Number of surface co-ordinates	NSC	I2	2
X-co-ordinates, Y-co-ordinates	SX(I) SY(I)	2F8.3 2F8.3	42.000 30.000 242.000 30.000
Soil density Saturated soil density	PB1 PB2	2F8.3	110.000 130.000
Soil friction Wall friction	QS QWS	2F8.3	0.520 0.400
Soil cohesion Wall adhesion	CB CA	2F8.3	0.000 0.000
Foundation soil friction Base friction	QFS QWFS	2F8.3	0.520 0.400
Allowable B.C. Maximum B.C.	QØ QNCMAX	2F8.3	5000.0007500.000
Base adhesion	CFOUND	F8.3	0.000
Front ground co-ordinates	XFRONT YFRONT	2F8.3	6.000 22.000
Front ground angle Front surcharge	ANGFRT QFRONT	2F8.3	0.000 0.000
Water level in backfill	WATERB	F8.3	29.000
Stem thickness Base thickness	TSTEM TBASE	2F8.3	1.500 2.000
Automatic design factors of safety	DFSTIP DFSLID DFSBCY	3F8.3	2.000 2.000 1.000
Height of soil to be retained	HFRONT	F8.3	8.000
Backfill surcharges	SURCH(I)	F8.3	100.000
Wall density	WALDEN	F8.3	150.000

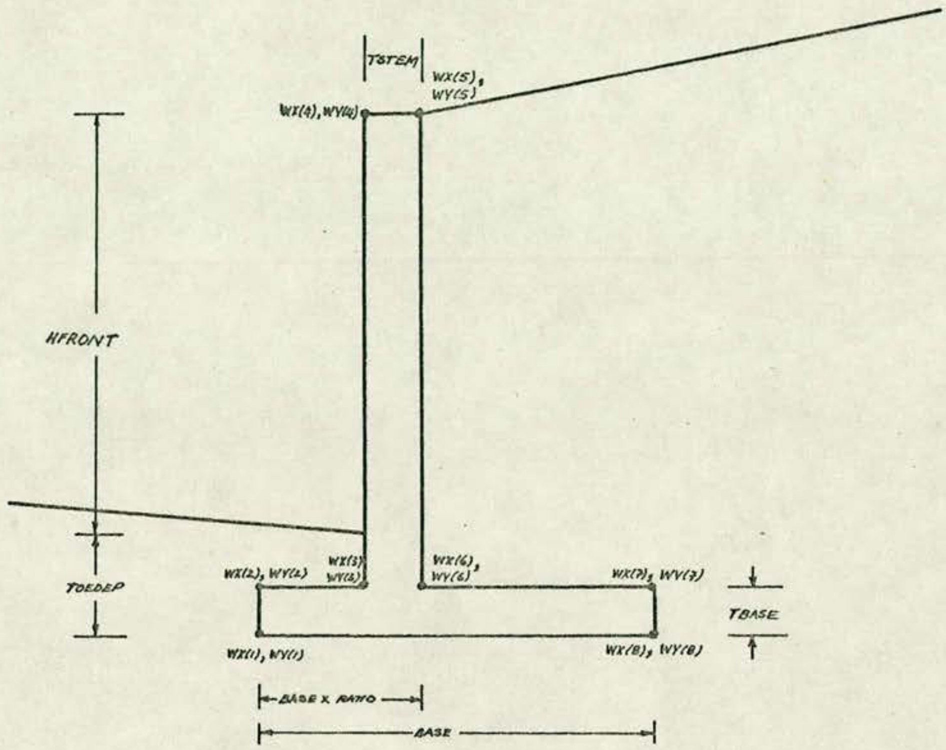


FIG. 5.3. : WALL SHAPE FOR AUTOMATIC CANTILEVER DESIGN

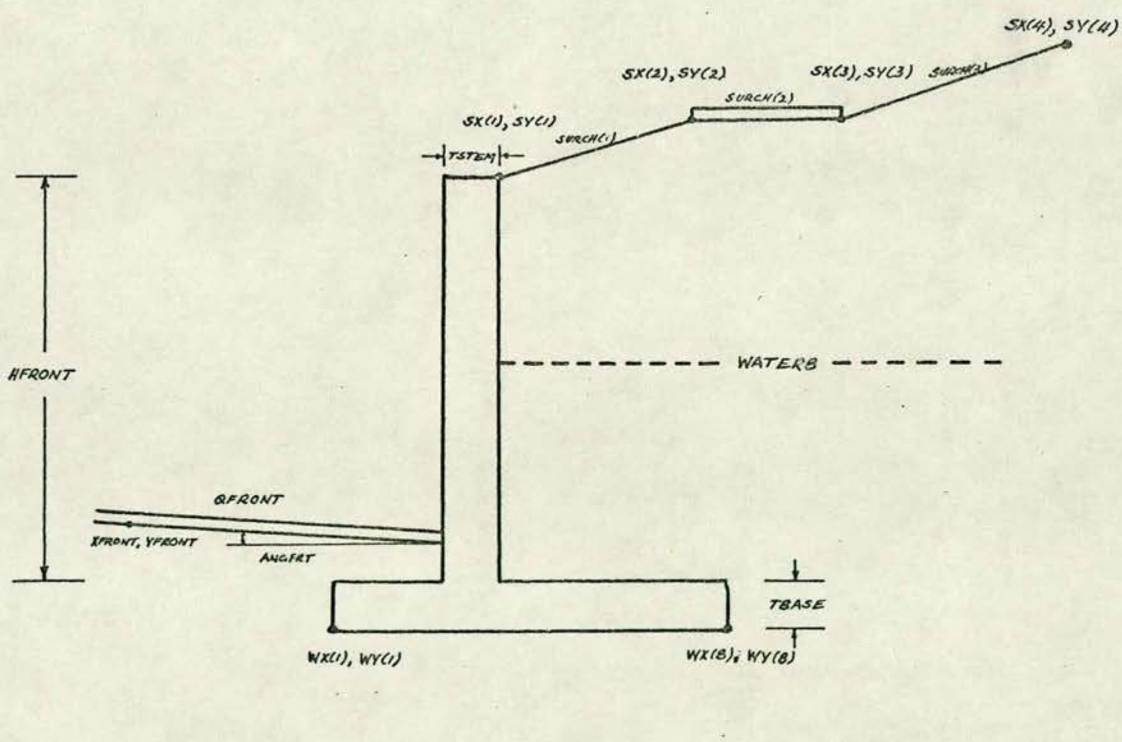


FIG. 5.2. : INPUT DATA

5.2.2.1 Select method for data input

The method of data input, manual or data file, is selected from a menu using the horizontal cross-hair.

5.2.2.2 Manual input of data

The manual input of data is controlled by a series of program prompts. The input is self explanatory and there is no need to follow any prescribed format.

5.2.2.3 Data input via data file

When data input is to be via data file the program will request the name of the data file. Only the first part of the filename need be input - the file will be assumed to have the filename extension .DAT. The layout of the data file must follow the prescribed format shown in Figure 5.1. The majority of the terms in this figure are self explanatory. These are illustrated in Figure 5.2.

The term maximum bearing capacity may be confusing. The value for the bearing capacity of the foundation material should be the allowable bearing capacity for the soil. When estimating the safety of the wall against bearing failure the allowable bearing capacity can be increased to make allowance for the depth at which the wall is founded, however to ensure that the amended value stays within limits the designer should specify an upper limit for the allowable bearing capacity and this is entered as the maximum bearing capacity.

The terms XFRONT, YFRONT refer to co-ordinates defining any point that lies on the surface of the ground in front of the wall. Only a plane ground surface is permitted in front of the wall and this must be defined by two co-ordinates, (XFRONT, YFRONT) and an angle ANGFRT.

The thickness of stem (TSTEM), thickness of base (TBASE), design factors of safety (DFSTIP, DFSLID, DFSBCY) and height of soil to be retained are all terms that are required if the automatic cantilever design procedure is to be used. Values must be input irrespective of whether this analysis process is to be used.

5.2.2.4 Formation of basic data array

As already discussed (chapter 4, sections 4.4.3 and 4.4.8.5) one of the interactive facilities offered by the program is for the change of the basic program data. To simplify this process an array, BASIC(I), containing all the basic data terms is formed. As will be seen in section 5.3.11 the menu selection process is made considerably easier by communication with the data array instead of directly with each data term.

5.2.2.5 Data check

The data check procedure has already been discussed in chapter 4, section 4.4.3.

Two routines are used to provide the checking facility. DATOUT outputs a list of wall and surface co-ordinates, and values of the basic data terms (Figure 4.7). Subroutine DATACH provides the facility for changing the values of any of the basic data terms. These provisions are kept in routines because at the main user interaction stage of the program these facilities are also made available.

The data change facilities permit the user to make amendments to any of the basic data terms. If there are errors in any of the wall or ground surface co-ordinates these cannot be changed at this time and it is necessary to run the program through irrespective of the errors and to use the manual interaction facilities to make the desired changes (see subroutine SCREEN).

5.2.2.6 Automatic formation of data file

Where the user has input the data manually, after having made any necessary amendments via the data check and change processes, the program will ask if the user wants the data stored as a data file for future reference. When a data file is required the user must specify the name for the file. The program will store the data file in the users disk area and give the file the file name extension .DAT.

5.2.3 Specification of design factors

5.2.3.1 Units : metric or imperial

The user must inform the program of which sort of units are to be used by typing M (METRIC) or I (IMPERIAL). This will permit the program to evaluate the terms whose values depend upon the units being used. These terms are:-

(i) PWATER : unit weight of water

(ii) BASLIM : smallest acceptable value for the base width in automatic cantilever design

(iii) DEPTHB : limiting depth for increase in bearing capacity due to depth beneath surface

(iv) BASEBC : limiting base width below which the allowable bearing capacity must be reduced

5.2.3.2 Weight of soil above toe

If the designer wishes this term to be included in the analysis then the flag TOEFCT is set equal to 1.0 otherwise it is given a value of zero. Before calculating the weight of soil above the toe the value of this flag is checked. If found to be zero the weight of soil above the toe is set to zero and the program abandons any toe weight calculation and goes straight on to the next stage.

5.2.3.3 % of passive pressure

The term APPLE is used to control the amount of passive pressure that can be used in stability calculations. This term should be input by the user as a percentage and is then converted by the program into a fraction. The passive pressure calculated by the program is scaled by this factor before inclusion in stability calculations.

5.2.3.4 Wall back drainage

Two conditions are considered:-

(i) water gathers in tension crack behind wall

(ii) water does not gather in tension crack behind wall

For the first case water forces on either side of the assumed failure wedge will cancel each other out and the water force should not be included in the consideration of wedge equilibrium. This is accomplished by setting DRAIN 1 = 0.0. The water force should however be considered when dealing with wall stability and this is ensured by setting DRAIN 2 = 1.0.

When the second case prevails the water force should be included in the consideration of wedge equilibrium, and DRAIN 1 is set to 1.0. The water force should not be considered when dealing with wall stability and DRAIN 2 is set to zero.

5.2.3.5 Base key

When the user requests a base key subroutine KEYS is summoned. This subroutine contains the user prompts and interactive commands for input of the depth of the base key DEPKEY and width of the base key WIDKEY.

5.2.4 Selection of analysis method

5.2.4.1 Simple or included wedge analysis

Whether or not the user proposes to analyse a cantilever type of wall it is necessary that he specifies which type of analysis procedure is to be used in the event of such a section being met.

Specification of method, Simple or Included Wedge, is done by selection from a two line menu with the horizontal cross-hair. The program remembers which method was selected by setting the logical variable SIMPLE as .TRUE. for Simple analysis and .FALSE. for Included Wedge Analysis.

5.2.4.2 Manual or automatic design for cantilever walls

If the user requires automatic cantilever design he should type Y to the message 'IS AUTOMATIC CANTILEVER DESIGN REQUIRED?'. This will cause the logical variable MANUAL to be set as .FALSE. When automatic design is not required MANUAL is set as .TRUE.

5.2.5 Input of data for automatic cantilever design

The form for the input of data specifying the limits of the automatic design of cantilever walls has already been discussed (chapter 4, section 4.4.5).

From the point of view of the programming the scope for the automatic analysis is stored as -

(i) Toe depths:

The number of toe depths for analysis is stored as NTOED. The initial value for the toe depth is TOE1 and the required toe depth increment is DELTOE.

(ii) Toe:base ratios:

The number of ratios to be analysed is NRATIO. The ratios can be input in any order. The program will automatically arrange them into ascending order before storing them in the array RATIOS( ). It is necessary to keep them in an ordered fashion so that the results can be used for graphical output.

5.2.6 Set variables to initial values

Before any part of the analysis process is embarked upon certain variable terms have to be given initial values. Three types of term are involved. These are terms that will be used several times throughout the program and which will only be changed if a change is made to the basic data e.g. TANQS, SLOPEF, CFRONT, BASTOP, BASLOW.

The second type of term is that used either as a count or limit during the program. It is necessary to set some of these terms to their initial values at the start of the program, e.g. OVMIN, OVMAX, IRES, KOUNTS.

The final type of term is one which may or may not be used in the program depending upon the analysis required. These terms are used in equations towards the end of the program and are set to zero now in case they are not defined later in the program, e.g. ADHTOP, ADHANG.

5.2.7 Automatic cantilever design : establish wall co-ordinates

For the automatic design of cantilever walls the wall is assumed to have an overall shape as shown in Figure 5.3. The height of soil to be retained, HFRONT, the stem thickness, TSTEM, and the base thickness TBASE are all input as part of the initial data.

All wall co-ordinates are worked out from the top of the back of the stem. The wall co-ordinates of this point are assumed to be the same as the co-ordinates of the first point on the backfill surface.

The wall co-ordinates are evaluated in three stages:-

(i) Fixed co-ordinates:

WX(3), WX(4), WX(5), WX(6), WY(4), WY(5)

These co-ordinates are the first to be set by the program and remain fixed during the complete automatic design procedure.

(ii) Co-ordinates that vary with toe depth:

WY(1), WY(2), WY(3), WY(6), WY(7), WY(8)

The y-co-ordinates of all the points defining the shape of the base vary only with the value of toe depth: their values are irrespective of the toe:base ratio.

(iii) Co-ordinates that vary with the toe:base ratio:

WX(1), WX(2), WX(7), WX(8)

The x-co-ordinates of the points defining the base extremities vary with the toe:base ratios. These are the last co-ordinates to be evaluated.

5.2.8 Examine front of wall conditions

5.2.8.1 Establish intersection of ground with wall face

Before a decision can be taken as to which method is to be used for calculation of passive pressure it is necessary to establish the co-ordinates of the point of intersection of the ground in front of the wall with the wall face (XWLFRT, YWLFRT). This point will vary depending upon the shape of the front of the wall and the nature of the ground surface in front of the wall. As both these surfaces can be varied during the running of the program their intersection point cannot be pre-specified but must be found by the program.

Once the point has been found the shape of the wall below the ground surface will be known and the method to be used for calculating passive pressure can be chosen.

5.2.8.2 Calculation of weight of soil above toe

When the face of the wall beneath ground level is not plane the passive pressure is calculated on a vertical plane through the toe. For such cases it is necessary to calculate the weight of soil above the toe WTOE, and to establish the x-co-ordinate of the centre of gravity of this soil mass, XWTOE.

If the user had previously opted to exclude the soil weight above the toe from stability calculations TOEFCT will have been set to zero and this will cause WTOE to be set to zero, and the program to go straight to the passive pressure calculation stage.

5.2.9 Rankines method for passive pressures

If the user has already indicated that no passive pressures are to be included in the stability calculations (APPLE = 0.0) the passive force PASIVE is set to zero and no calculation is carried out.

When passive pressure is to be calculated using Rankine's method it is considered initially in two parts: PASIVE, the passive force due to the soil in front of the wall and PASIVQ the passive force due to any surcharge in front of the wall. Once the position of the resultant force on the front of the wall has been established the two components are combined and the overall resultant stored as PASIVE.

When the wall contains a base key it will also be necessary to calculate the amount of passive pressure that can be mobilized in front of the wall assuming full passive pressure is developed in front of the base key. Again the passive force is considered in two parts, PASKEY and PQSKEY. This will enable the point of application of the overall resultant force to be found. The overall resultant is then stored as PASKEY.

5.2.10 Friction circle calculation of passive pressure

The friction circle method for the calculation of passive pressure is a fairly lengthy procedure and has been completely contained within the subroutine FRICLE. A description of this subroutine is given in section 5.3.7.

5.2.11 Consider wall factors

Three factors must be known about the wall: the wall weight (WWALL), the x-co-ordinate of the centre of gravity (XWALL) and the angle of the wall base (AGBASE). The wall is divided into a series of vertical strips for the purpose of weight calculation. Subroutine COG is then used to calculate the area of each strip and the moment of each strip about the origin. The wall weight can be found by multiplying the summation of the strip areas by the wall density WALDEN.

5.2.12 Consider tension cracks

The depth of tension crack that will form at the surface of a cohesive deposit under active pressure conditions is given by a formula

$$HO = \frac{2.0 * C * \tan(45 + \phi/2)}{\gamma}$$

where C = cohesion of soil

ϕ = angle of internal friction

γ = soil density

The depth is independent of the slope of the backfill surface, however if the backfill is subjected to a uniformly distributed load q the tension crack will be

$$HO = \frac{2.0 * C * \tan(45 + \phi/2)}{\gamma} - \frac{q}{\gamma}$$

This reduction in depth is only considered when the ground surface is plane. If the ground surface is irregular and is subject to discontinuous lengths of surcharge some reduction in tension crack depth will be found beneath and adjacent to the loaded areas. However the vertical pressures in the soil due to the presence of the surcharge are distributed laterally as the depth beneath the ground surface increases. The actual conditions are complex and any attempt at adjusting the depth of the tension crack could only be approximate. Consequently where surcharge loads are discontinuous no adjustment is made to the surcharge depth.

If the tension crack depth is found to be greater than the height of earth to be retained the user is informed by the message

** TENSION CRACK GREATER THAN HEIGHT OF SOIL
TO BE RETAINED **

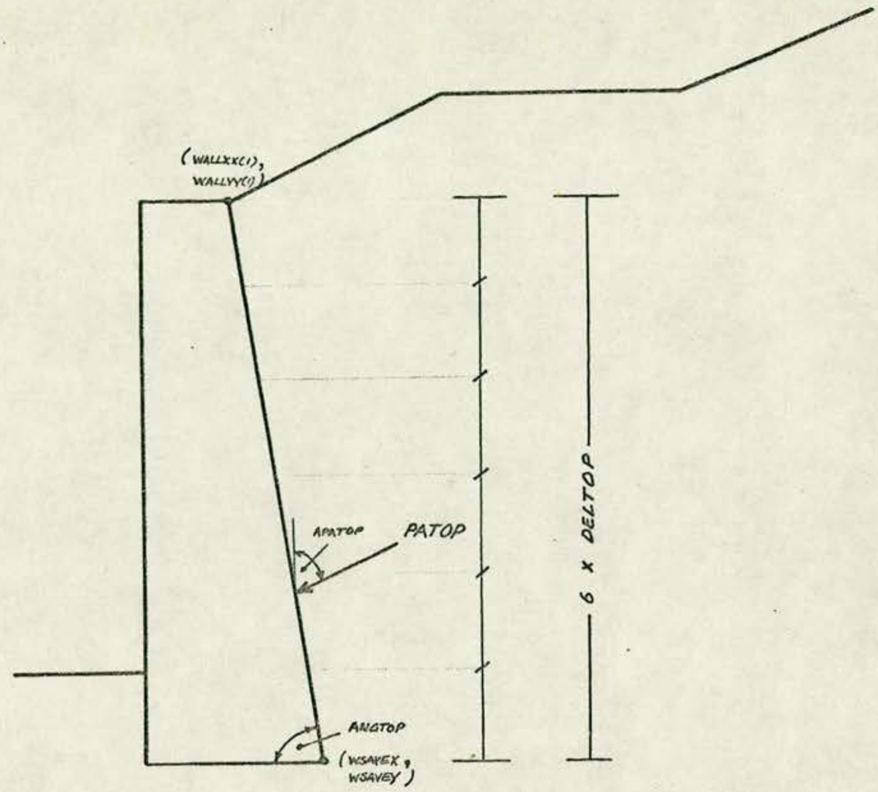
and the program will move straight on to the interactive stage thereby permitting the user to decide what to do next.

5.2.13 Determine shape of wall back

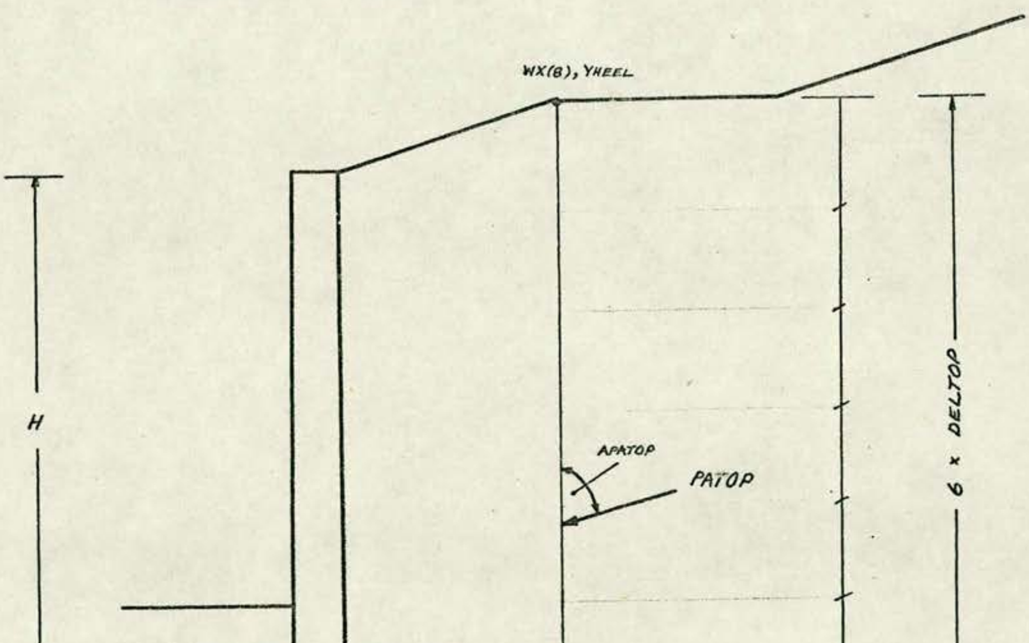
5.2.13.1 Plane wall back

The wall back is divided into six equal elements, each of height, DELTOP, for the calculation of active earth pressure. The wall back is plane and there is therefore no bottom part for analysis, DELBOT = 0. (Figure 5.4A).

When the SIMPLE analysis procedure is being used to find the active force on a vertical plane through the heel, i.e. when flag SIMON is true, (Figure 5.4.B) this is treated in the same way as a wall with plane back.



a. gravity wall



b. simple analyis of cantilever wall

FIG. 5.4. : PROGRAM NOTATION FOR PLANE WALL BACK

The only peculiarity is the angle for the active force PATOP. This is no longer given by ANGTOP - QWS but is equal to ANGSIM, the angle calculated using method suggested in the AREA manual(2) and discussed in chapter 2, section 2.3.5.3.

5.2.13.2 Bi-planar wall back

Each part of the wall back is divided into three parts for the calculation of active earth pressures. Figure 5.5. The vertical increment for the top part is DELTOP and the bottom increment is DELBOT.

The co-ordinates of the break in the wall are saved as WSAVEX, WSAVEY.

If the backfill material is cohesive when the program analyses the pressure on the bottom surface wall adhesion along the bottom part should be included in the consideration of wedge equilibriu, CTERM is therefore set to the value of wall adhesion CA.

5.2.13.3 Tri-planar wall back

When the wall back is made up of three planes a check is made to see if included wedge analysis could be used. This is done first by comparing the slopes of the top (SLOPE 1) and middle (SLOPE 2) sections of the wall back. If the middle part of the wall is steeper than the top part no included wedges could form and the wall is analysed as a bi-planar wall with a heel projection (Figure 5.6). Following the completion of the analysis on the top and middle sections the bottom section is

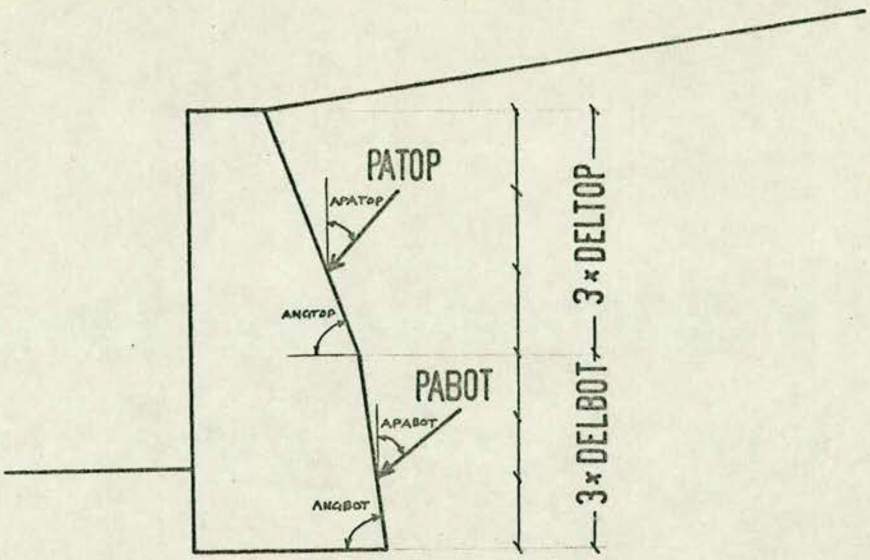


FIG. 5.5. PROGRAM NOTATION FOR BI-PLANAR WALL BACK

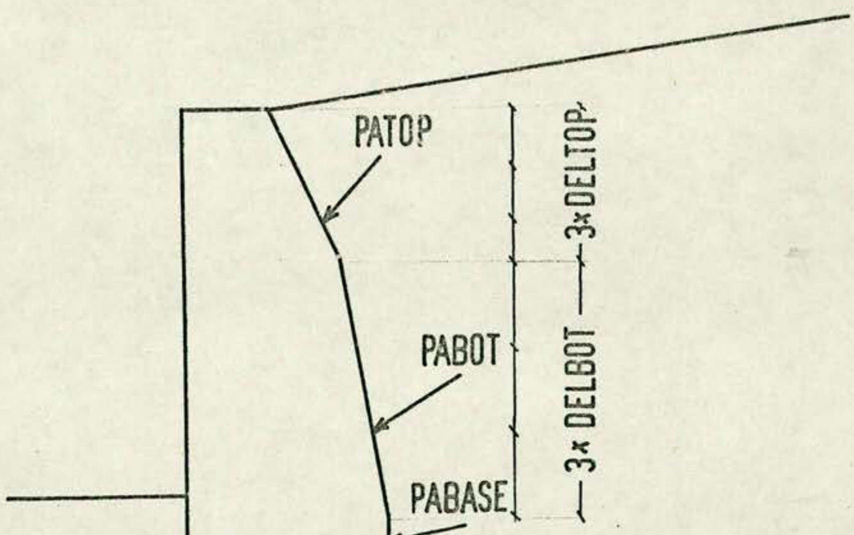


FIG. 5.6. : BI-PLANAR WALL WITH HEEL PROJECTION

considered as one additional element. Where the slope of the middle section is less steep than the top section an included wedge may form (Figure 5.7) and further checks are necessary.

As discussed in chapter 3, section 3.2.3.4 the included wedge failure surface must make an angle greater than ϕ with the horizontal. A check is made therefore to find out if such a failure surface could form or whether it is impossible because the slope of the middle section is steeper than tan ϕ .

If this surface can not form the program proceeds straight to the next point. However where such a surface can form a check must be made to find out whether there is space between this surface and the bottom of any tension crack for an included wedge surface to develop. That is to say the level of the bottom of the tension crack, ZHO , must not lie beneath the y-co-ordinate of the point of intersection of the smallest acceptable wedge failure surface with the wall back, YTAN. If ZHO is found to be less than YTAN the program outputs the message

** TENSION CRACK TOO LARGE FOR INCLUDED WEDGE
ANALYSIS : TRY SIMPLE **

and will then return to the analysis selection stage.

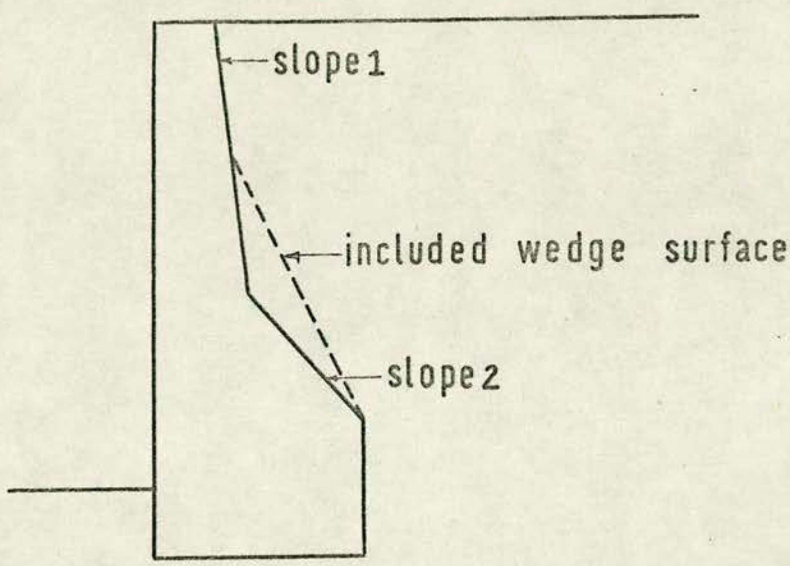


FIG. 5.7 : FORMATION OF INCLUDED WEDGE SURFACE

5.2.14 Simple analysis : establish effective wall back

When the SIMPLE analysis procedure is to be used instead of included wedge analysis the vertical surface through the heel of the wall has to be considered as an effective wall back. It is necessary to find the y-co-ordinate of the intersection of the vertical surface with the ground surface, YHEEL. A record must also be made of the weight of any surcharge above the heel, SHEEL, and the moment of this surcharge about the origin AMHEEL.

The program will calculate the weight of soil above the heel, add to it the weight of any surcharge above the heel and store the result as SWWT. The x-co-ordinate of the centre of gravity of this force is calculated and stored in SWXBAR.

As already discussed (chapter 2, section 2.3.5.3) the line of action of the active force on the vertical through the toe is estimated by drawing a line between the top of the wall and a point on the surface of the backfill at a horizontal distance of twice the height of the wall from the wall back. The active pressure is assumed to act parallel to this line. The angle is calculated as the angle made with the vertical and is stored as ANGSIM.

5.2.15 Specification for included wedge analysis

The increments for the included wedge analysis are fixed by dividing the height in which the included wedge may intersect the back into six sections. Each section is of height DLTAZ 1 where DLTAZ 1 = (ZHO - YTAN)/6.0.

Figure 5.9a. The y-co-ordinate of the intersection of the wall back with the included wedge outer surface is stored as Z1. This is initially stored as Z1 = ZHO + DLTAZ1.

The term CTERM is used to distinguish between wall adhesion and soil cohesion when considering an included wedge analysis. In Figure 5.8 the six points from which trial wedge analysis are carried out are shown. Possible failure surfaces are drawn-in for points (2) (Figure 5.8a) and (5) (Figure 5.9a). The resulting force polygons for these wedges are shown in Figures 5.8b and 5.9b.

The equation for the calculation of PA is standard for all wedges. For wedges from points (1), (2) and (3) the wall adhesion between the bottom of the tension crack and point (3), ADHTOP, is zero. So also is TOPSA the resultant active force on this surface. The term ADHESN is used for the cohesion or adhesion force developed along the lower part of the effective wall back, and is calculated as length of effective wall back x CTERM. Therefore when considering the upper portion of the wall back CTERM has the value of soil-wall adhesion CA. and if considering the lower part of the effective wall back CTERM has the value of the soil cohesion CB.

A count is maintained of how many included wedges have been analysed in the term KOUNT. This is set initially to zero.

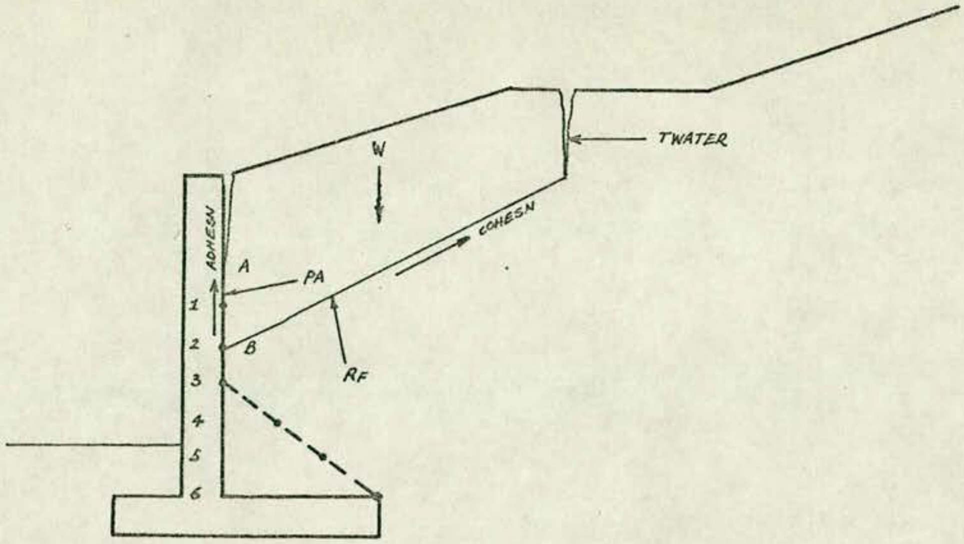


FIG. 5.8.a. : TRIAL WEDGE FOR POINT ON TOP PART OF WALL

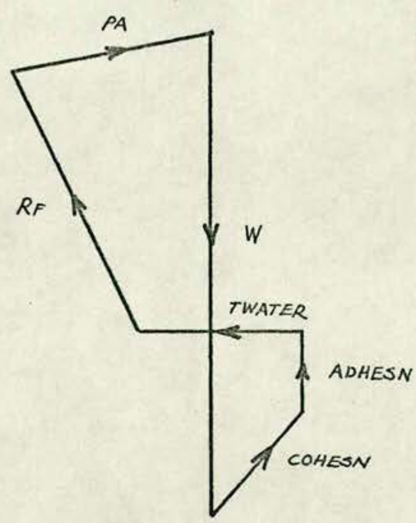


FIG. 5.8 b. : FORCE POLYGON FOR TRIAL WEDGE

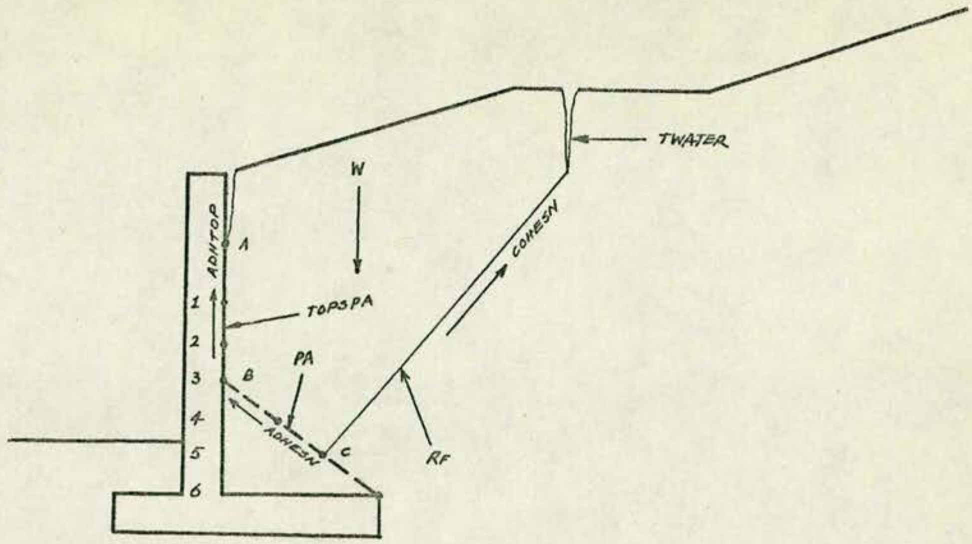


FIG. 5.9a.: TRIAL WEDGE FOR POINT ON INCLUDED WEDGE SURFACE

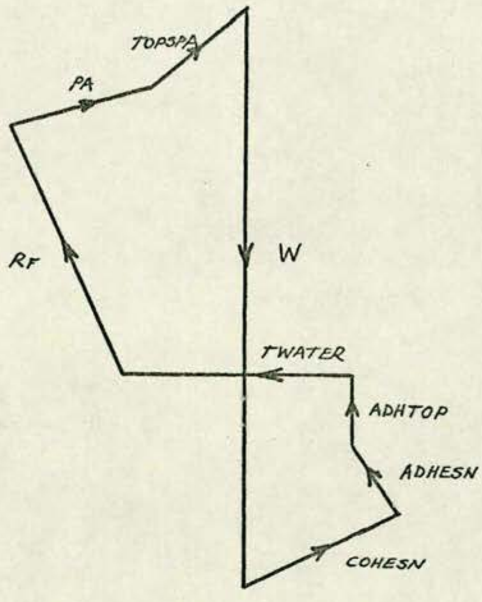


FIG. 5.9 b. : FORCE POLGON FOR TRIAL WEDGE

5.2.16 Incrementation of included wedge analysis

For each included wedge shape it is necessary to establish the point of intersection of the included wedge with the wall back. The co-ordinates of this point are stored in (WSAVEX, WSAVEY). The angle of the included wedge with the horizontal, WEDANG, is also the angle of the lower part of the effective wall back ANGBOT.

The angles for the resultant active pressure on the top and bottom parts of the effective wall back APATOP, APABOT, are established.

When the final included wedge is being considered (KOUNT = 6) a check is made to see if the final surface is in fact the lower part of the wall back. This will be the case when the slope of the lower part of the wall (SLOPE 2) is greater than the limiting included wedge slope TANQS. When this occurs CTERM is reset to the wall adhesion CA.

5.2.17 Specification for numeric differentiation

Once the shape of the wall back has been established it is divided up into sections for trial wedge analysis. This process permits a numeric differentiation technique to be used to find the point of application of the active earth force on the wall.

The wall back is divided into six parts for this process. If the wall back is plane each part is of vertical height DELTOP. Where the wall back contains a break each wall element is divided into three increments of height DELTOP for the top part and DELBOT for the lower part.

A record of which wall increment is being analysed is kept in NZCTRL and this is initially set to zero.

The active force on the top part of a wall with a bi-planar back is stored as TOPSPA and the angle of this force as TOPSC. Both these terms are initially set to zero.

The current y-co-ordinate of the point on the effective back from which the trial wedge analysis is being carried out is stored as Z. This term is initially given the value of the effective top of the wall, WALLYY(1), an allowance having been made for any tension cracks.

5.2.18 Incrementation for numeric differentiation

The y-co-ordinate of the point from which the trial wedge analysis is carried out, Z, is lowered by DELTAZ for each stage of the numeric differentiation analysis. When the top part of a bi-planar wall is being considered DELTAZ has the value DELTOP, and for the bottom part a value of DELBOT.

For each stage of the analysis the count NZCTRL is incremented by one.

Once the value of Z has been established the co-ordinates for the part of wall to be analysed must be transferred to the arrays WALLXX( ), WALLYY( ). Initially values are given for the overall wall shape according to whether the wall is plane or bi-planar. These values are then amended to make the base of the wall correspond to the level given by the value of Z. The number of wall coordinates used to define the part of wall being analysed is stored as

NOBC (Number of Back Co-ordinates). When the program comes to analyse the trial wedge from the break in the wall back the following check is enforced

IF (NZCTRL . EQ . NLIM1) Z = WSAVEY

This check was found to be necessary because the subtraction of three times the term DELTOP from the top of a bi-planar wall would not always give the exact value for the y-co-ordinate of the break in the wall because of rounding corrections.

5.2.19 Trial wedge analysis

5.2.19.1 Set angle of wedge base, S

The angle of the base of trial failure wedges is determined by the angle the base makes with the horizontal, S. This angle is initially given a value of 90°.

The search for the critical wedge is a two stage process. Initially a coarse search is made with the value of S being reduced in 10° increments (DELTAS). Once the critical value for the active force is found the corresponding value of S is increased by 20°, the value of DELTAS reduced to one degree and the search for a critical value repeated.

Initially the critical value for the active force PASAVE, is set at -100000.00. After all subsequent analyses the calculated value for the active force, PA, is compared with the current critical value, and if greater than the critical value replaces the critical value. It is found that as the angle of S falls, the value of PA steadily rises, reaches a maximum and then falls off. Consequently as soon as a value of PA is found to be smaller than PASAVE the search ceases, and the critical value of PA taken as PASAVE corresponding to a critical value of angle of wedge base of S + DELTAS.

5.2.19.2 <u>Find where wedge base cuts ground surface and value of SURWT</u>

Initially the presence of any possible tension crack is neglected by the program and the intersection of a plane wedge base with the ground surface is considered. The co-ordinates of the point of intersection are found by calculating the intersection point of the line of the wedge base with each of the lines defining the ground profile starting from the wall back and working away from the wall. Having found the point of intersection a check is made to see if in fact this point lies within the limits of the surface element. If it does the point is stored as (XSUR, YSUR) and the search is complete. When the point does not lie within the limits, the program will move on and consider the next surface element. Throughout the search a summation is kept of the surcharge weight acting above the wedge and is stored in the term SURWT.

If on completion of the above procedure there is found to be a tension crack present the subroutine CRACKS is called. This subroutine works back from the point (XSUR, YSUR) to find at what point the tension crack will fit in between the ground surface and the wedge base.

The co-ordinates XSUR and YSUR are then reset and the value of SURWT adjusted if necessary.

5.2.19.3 Calculate weight of trial wedge

The trial wedge shape is considered as being made up of a top and bottom surface for the point of view of calculating it's weight. Both surfaces run from the top of the effective wall back (WALLXX(1), WALLYY(1)), to the point where the wedge base intersects the ground surface (XSUR, YSUR). The top surface runs along the ground surface while the bottom one runs down the effective wall back and along the wedge base.

The co-ordinates of each point on the top surface are transferred to the arrays XTOP( ), YTOP( ) and those on the bottom surface to the arrays XBOT( ), YBOT( ). The subroutine STRIPS is then called to divide the shape into a series of vertical strips. Subroutine WEIGHT can then be used to calculate the weight of the trial wedge, SUMWT.

5.2.19.4 Calculation of resultant active force

The calculation of the cohesive force along the wedge base COHESN is straightforward, and is simply the wedge base length times soil cohesion. The calculation of the force ADHESN is not as straightforward.

As already mentioned above and illustrated in Figures 5.8a and 5.8b the force ADHESN is used for either the adhesive force between the soil and the back of the wall or the cohesive force along the included wedge failure surface.

When the SIMPLE analysis procedure is being used there will be no such force and ADHESN will be set to zero.

When included wedge analysis is being used or the wall is a gravity type the calculation of ADHESN is governed by the value of ADCTRL. When ADCTRL = - 1.0 the active pressure is being considered directly against a plane wall surface and ADHESN represents the adhesion force between the soil and wall.

When ADCTRL = 0.0 the middle section of a wall is being considered. This could be either the included wedge part of a cantilever wall or part of gravity wall. However the value of CTERM will determined which case is prevalent. When ADCTRL = 1.0 the active pressure against the heel projection of a cantilever or gravity wall with bi-planar back is being considered. ADHESN then represents the adhesive force between this surface and the backfill.

Having established the values of the terms COHESN and ADHESN an equation derived from the polygon of forces is used to find the value of PA.

For convenience the numerator, ANUM, of the equation is considered in two parts, PART1 and PART2. Most of the terms in the equation have already been discussed. The term A is the angle the wedge base makes with the vertical and B is the angle the reaction on the wedge base (FREACT) makes with the vertical. C is the angle the resultant active force PA makes with the vertical.

5.2.19.5 Check value of PA

Before the calculated value for PA is acceptable for comparison with PASAVE it is necessary to check its validity. Under some circumstances when dealing with small depths of cohesive soil PA has been found to take on a negative value. Similarly the value of FREACT the reaction on the wedge base sometimes assumes a negative value. Both these conditions arise because the soil cohesion term COHESN has a value greater than the weight of the soil wedge weight. Neither condition is acceptable in practice and when they occur the current value of PA is set equal to - 100000.0.

Having carried out these checks the value for PA is compared with the current highest value PASAVE. When PA is greater than PASAVE, PASAVE is updated to the current value of PA and the program returns to consider the next failure wedge.

When PA is found to be less than PASAVE the wedge analysis for that particular search is complete. If the program is already using the fine increment for S, i.e. DELTAS = 1°, the value for the resultant active pressure on the wall back has been found and is stored as PASAVE.

If the program is still on the 10° increment the angle of the wedge base is reset as S + 20°, the increment for S is set to 1°, PASAVE reset to - 100000.0 and the search procedure repeated.

5.2.20 Ascertain current position of analysis process

Having completed the calculation of the active force it is necessary to establish the current position of the analysis process.

If THIRD is true the program will have just completed calculation of the active pressure on the heel projection of a cantilever wall or gravity wall with tri-planar back. In such a case the program has only to store the results of this analysis before proceeding to consider the wall stability.

When THIRD is false a check is made on the level of the incrementation in the graphic differentiation process. If NZCTRL, the graphic differentiation count, has reached the value NLIM1 a check is made on the shape of the wall back. If the wall back has a break in it i.e. BACK = 0.0 or BACK = 1.0, the analysis of the top part of the wall has just been completed and the results are stored. The active earth force on the top part of the wall is stored as TOPSPA and its angle as TOPSC. At this stage it is also necessary to prepare for the analysis of the active pressure on the first part of the lower part of the wall by changing the number of back co-ordinates NOBC to 3, the angle of the wall back ANGLE to ANGBOT, and the vertical increment for graphic differentiation, DELTAZ, to DELBOT. The magnitude and angle of any adhesive force acting on the top part of the wall is transferred to ADHTOP and ADHANG.

When NZCTRL does not equal NLIM1 the above stage is by-passed, and the program passes straight on to storing the active force in the array ACTIVE ( ).

A check is then made to see if the incremental analysis for numeric differentiation is complete by considering the value of NZCTRL. If the incremental analysis is not yet complete the program returns to consider the next part of the wall.

When the incremental analysis is complete (NZCTRL = 6) a check is made on the shape of the wall back. If the wall back is plane or bi-planar the analysis process is complete and the program can move straight on to consider the wall stability.

When the wall back is tri-planar the weight of the included soil wedge, SWWT, is calculated if the included wedge method is being used. The program then considers the active earth pressure on the heel projection, PABASE.

5.2.21 Calculation of active force on heel projection

5.2.21.1 Set up initial conditions

Before embarking on the calculation of the active force on the heel projection PABASE, the existing results are rearranged. The active forces on the top and middle sections of the wall are combined into one resultant TOPSPA with angle TOPSC.

The forces currently stored as ADHTOP and ADHESN are combined and the resultant replaced in ADHTOP. The angle of this resultant is stored in ADHANG.

The number of wall back co-ordinates NOBC is set to four and the angle the heel projection makes will be vertical calculated and stored as ANGLE.

The flag THIRD is set as .TRUE. indicating that the program is now considering the active force on the third and final part of the wall back, the heel projection.

5.2.21.2 Store results for heel analysis

The resultant active pressure on the heel projection is stored as PABASE, the angle of the force as APABAS and the x-co-ordinate of the point of application as XPABAS. The vertical lever arm for the force, relative to the toe of the wall, is stored as YPABAS.

With completion of the heel analysis the flag THIRD is reset to FALSE and the terms referring to the adhesion on the top part of the wall ADHTOP, ADHANG reset to zero.

5.2.22 Establish point of application of active forces

The numeric differentiation technique for establishing the points of application of PATOP and PABOT is contained in the subroutine PAPA (section 5.3.9). This subroutine will return with the points of application of the resultant active forces as (XPATOP, YPATOP) and (XPABOT, YPABOT). The x-co-ordinates are real x-co-ordinates while the y-co-ordinates have been reduced to represent the vertical height above the toe of the points of application.

5.2.23 Calculation of water forces

Water pressures, like earth pressures, can be considered on a maximum of three wall back surfaces. The water forces are stored as PWTOP, PWBOT and PWBAS. These forces are automatically included in the equations for the calculation of wall stability.

Before a check is made to see if water pressures will be involved in the analysis, all the water forces, co-ordinates of points of application and lines of action are set to zero. If it is then found that the standing water level lies beneath the heel of the wall the program moves straight on to the calculation of factors of safety.

When the water level does intersect the wall back the procedure for establishing the resultant water pressures is as outlined in Figure 5.10.

Subroutine AQUA is used to calculate the water force on each part of the wall back. Before calling AQUA the top and bottom co-ordinates of the points of intersection of the water with the wall back element under consideration must be established and stored in XWT, YWT and XWB, YWB. From these co-ordinates, and water level WATERB, the subroutine will calculate the water force on the surface, PW, the angle of the force with the vertical APW, and the point of application of the force on the wall element XPW, YPW.

As shown in Figure 5.10 this process is repeated for as many wall elements as necessary with the results being stored as PWTOP, APWTOP, XPWTOP, YPWTOP for the top of the wall, PWBOT, APWBOT, XPWBOT, YPWBOT for the bottom part of the wall back and PWBAS, APWBAS, XPWBAS, YPWBAS for the heel projections.

5.2.24 <u>Calculation of factors of safety</u>

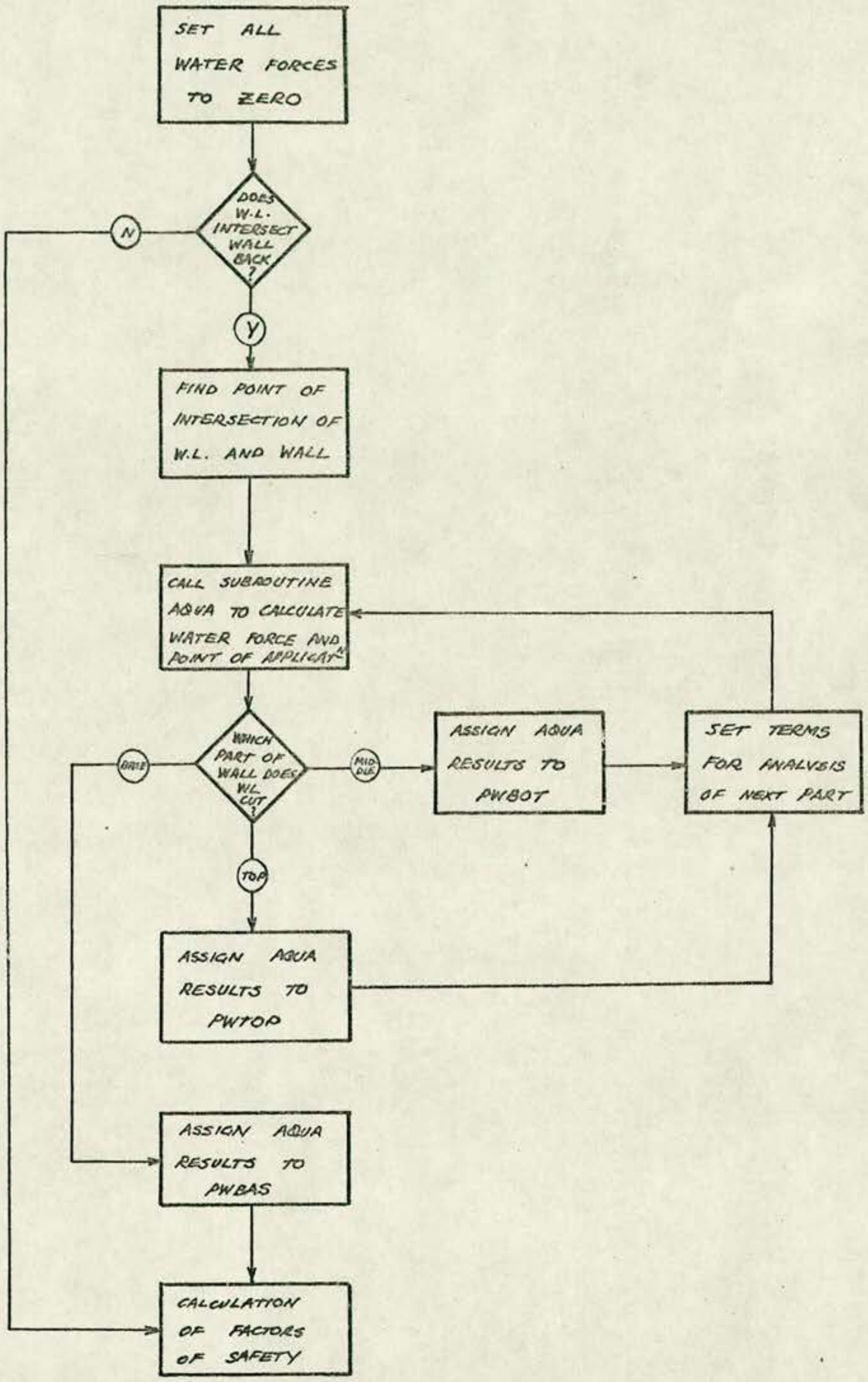


FIG. 5.10. : PROCEEDURE FOR CALCULATION OF WATER FORCES

5.2.24.1 Establish force lever arms

Before inclusion in the equations for calculation of the factor of safety against overturning, the horizontal distances of the points of application of the resultant earth and water pressures from the toe are calculated. The lever arms used are shown in Figure 5.11.

5.2.24.2 Calculate magnitude and eccentricity of resultant on base

The magnitude (R) and eccentricity (E) of the resultant on the base of the wall are found by taking moments abouts the toe of the wall of the forces shown in Figure 5.11. RN and RT represent the components of the resultant normal and tangential to the base.

The resultant R acts at a distance RARM from the toe and has point of application co-ordinates XBASE, YBASE.

5.2.24.3 Factor of safety against sliding

The factor of safety against sliding is calculated from the equation

$$\text{FSLID1} = \frac{\text{forces resisting sliding}}{\text{forces causing sliding}} = \frac{\text{STFOR}}{\text{SLFOR}}$$

where

STFOR : CFOUND x BASE + RN x TAN(QWS) + PASKEY x

COS (APASE - AGBASE)

SLFOR : RT, the tangential component of the reaction

on the base

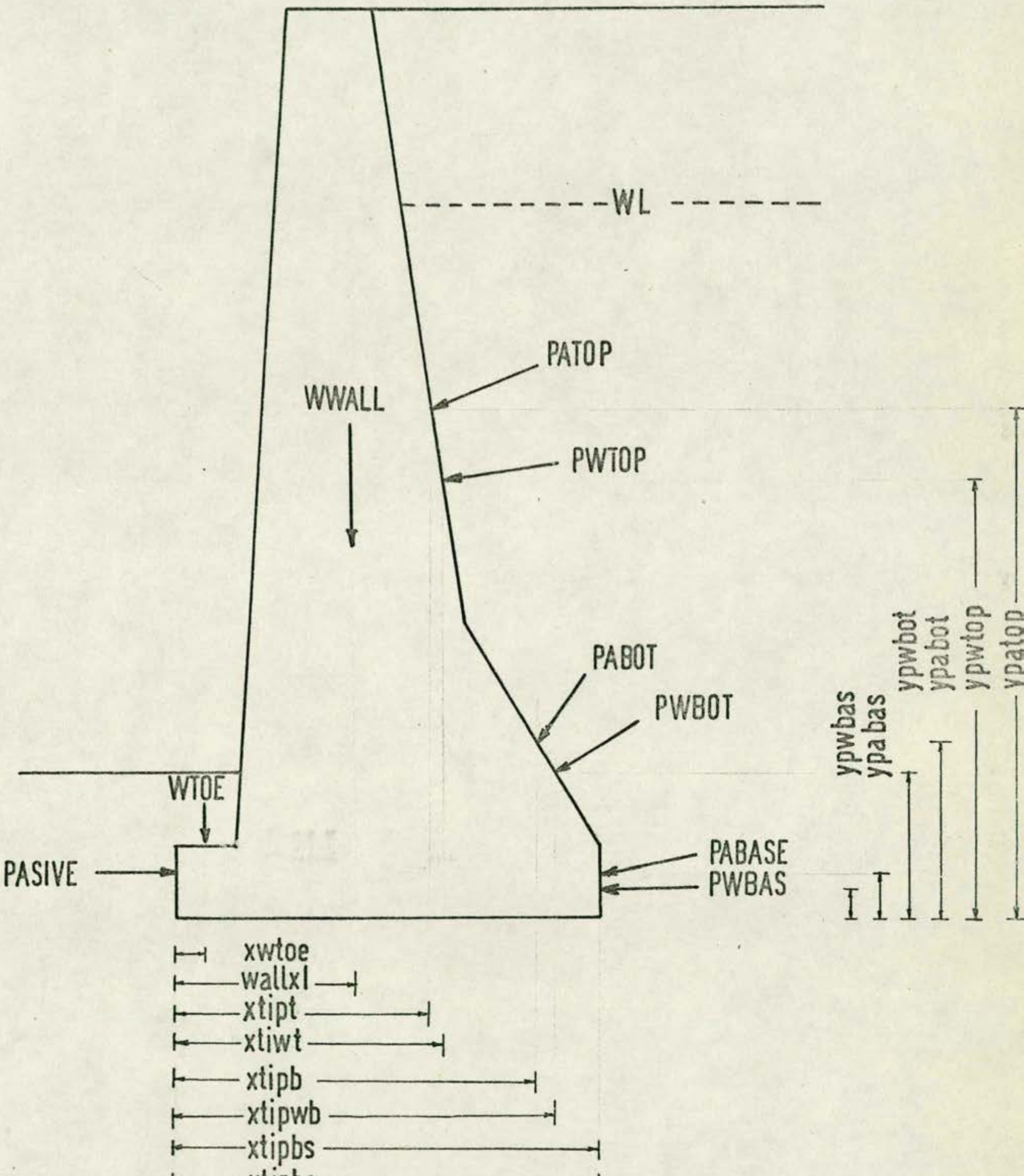


FIG. 5.11. : LEVER ARMS FOR STABILITY ANALYSIS

and

CFOUND : cohesion between base and underlying soil

BASE : width of base

RN : normal reaction on wall base

QWS : angle of friction between base and soil

PASKEY : passive force developed in front of the wall including any developed in front of a base key

APASE : angle of line of action of passive force with horizontal

AGBASE : angle of base with horizontal

If the sliding force SLFOR is found to be negative the factor of safety is given a value of 99.00.

When there is a base key present it is necessary to consider two failure modes as described in chapter 3, section 3.4.4. For the second failure mode a failure plane is assumed to develop between the toe and bottom of the key and this surface is considered as the effective base of the wall. It is necessary in this case to re-calculate the base resultant components RN and RT for the effective base surface. The factor of safety can then be calculated using the equation

$$FSLID2 = \frac{STFOR}{SLFOR}$$

where

STFOR : CB x BASE + RN x TAN (ANGFCT) + PASIVE x COS (APASE - AGBASE)

SLFOR : RT

and

CFOUND : cohesion of foundation material

BASE : length of effective base

RN : normal reaction on effective base

PASIVE : passive force that can be developed in front of the wall between the toe and the ground surface

AGBASE : angle effective wall base makes with horizontal

APASE : angle of line of action of passive force with horizontal

If two factors of safety are calculated the smaller factor of safety is taken as the factor of safety against sliding, FSLID.

The procedure described above is illustrated in the flow diagram in Figure 5.12.

5.2.24.4 Factor of safety against overturning

The stabilizing moment is considered in two parts. Forces which directly contribute to wall stability i.e. wall weight WWALL, weight of soil above the toe WTOE, included wedge weight SWWT and passive earth force PASIVE are considered in the stabilizing moment SM. The forces which tend to cause overturning are considered in component form; the overturning components form the moment OM while the stabilizing components yield moment OM1.

If there is found to be no net overturning moment the factor of safety is given a value of 99.00.

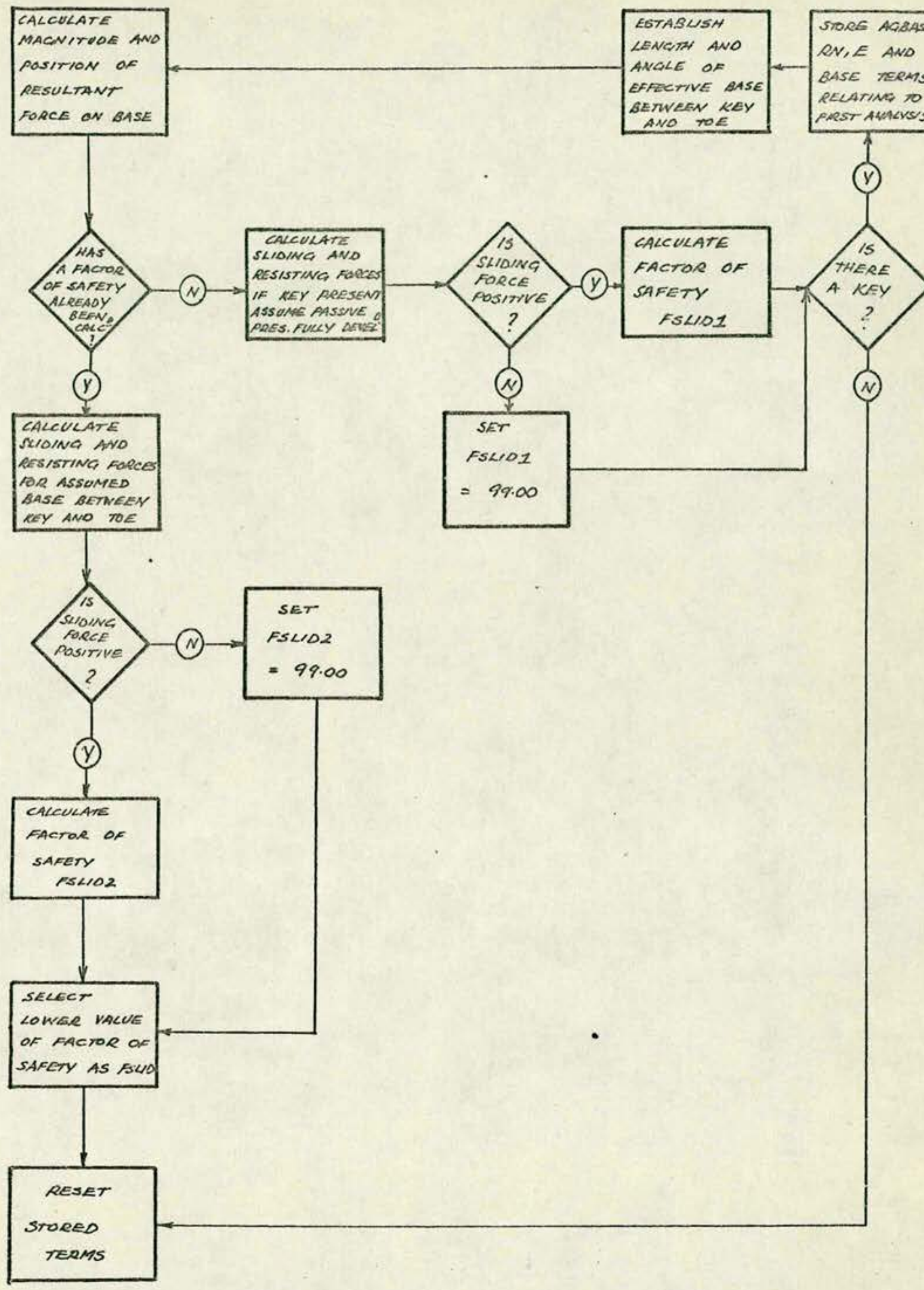


FIG. 5.12. : CALCULATE FACTOR OF SAFETY AGAINST SLIDING

5.2.24.5 Factor of safety against bearing failure

The procedure for calculating the factor of safety against bearing failure FSBCY is illustrated in Figure 5.13. The first part of the procedure (top part of Figure 5.13) is concerned with calculating the maximum bearing pressure BPRES beneath the wall. Four different cases are considered:

(i) Resultant lies within middle third of the base.

$$BPRES = \frac{RN}{BASE} * \left\{ 1.0 + \frac{6.0 * E}{BASE} \right\}$$

RN = normal resultant on base

E = eccentricity of normal from centre of base

BASE = base width

(ii) Resultant intersects base in outer third.

$$BPRES = \frac{4.0 * RN}{BASE - 2.0 * E}$$

(iii) Resultant intersects edge of base:-

BPRES = RN

(iv) Resultant lies outside base: wall unstable and factor of safety against bearing failure set equal to zero.

Once the maximum bearing pressure beneath the wall has been found it is necessary to calculate the value for the allowable bearing capacity QD. As discussed in chapter 3, section 3.5.3, the value for the allowable bearing capacity will depend upon the depth at which the

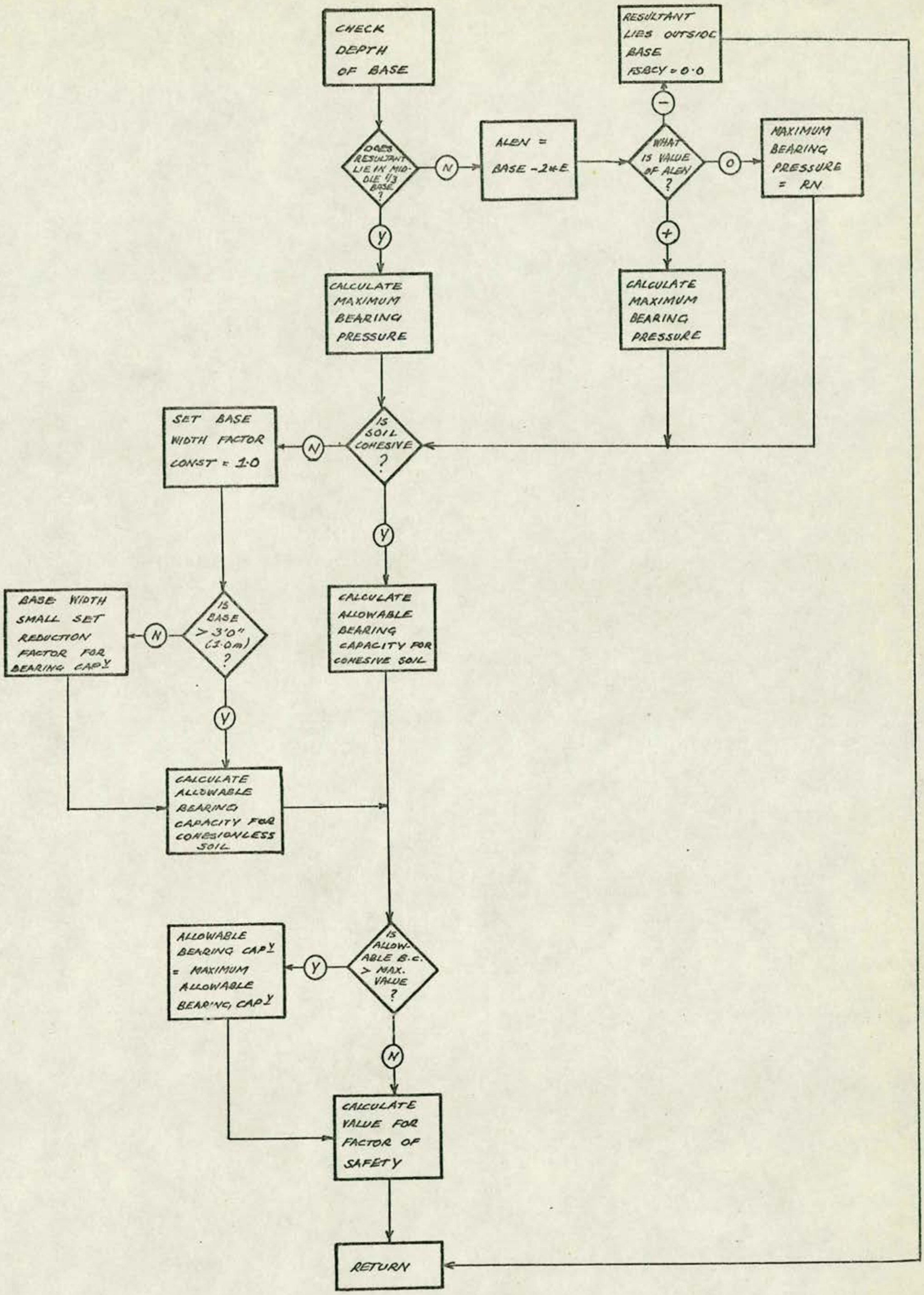


FIG. 5.13.: CALCULATION OF FACTOR OF SAFETY AGAINST BEARING FAILURE

base has been founded, the width of the base and the nature of the foundation material. The procedure for arriving at the value of QD is summarized in the flow diagram in Figure 5.13.

Once the allowable capacity has been found a check is made to ensure that the amendments have not made the value greater than the maximum permissible value QLIM. QLIM has a value of 1·5 times QØ, the allowable bearing capacity, for cohesive soils, and the value QNCMAX for cohesionless soils.

Finally the factor of safety FSBCY can be calculated as

$$\text{FSBCY} = \text{QD/BPRES}$$

5.2.25 Manipulation of factors of safety

If the included wedge analysis method is being used the calculated values of the factors of safety will require manipulating to establish the critical values for these terms. The procedure for this is outlined in the flow diagram shown in Figure 5.14.

If the section being analysed is the first included wedge surface the critical terms CRITSL, CRITTP, CRITBC are set equal to the calculated values for the factor of safety and the program returns to consider the next included wedge.

After subsequent included wedge analyses the calculated values for the factors of safety are compared with the current critical values. If found to be less than the critical values the critical values are reset to the new low value for the factor of safety.

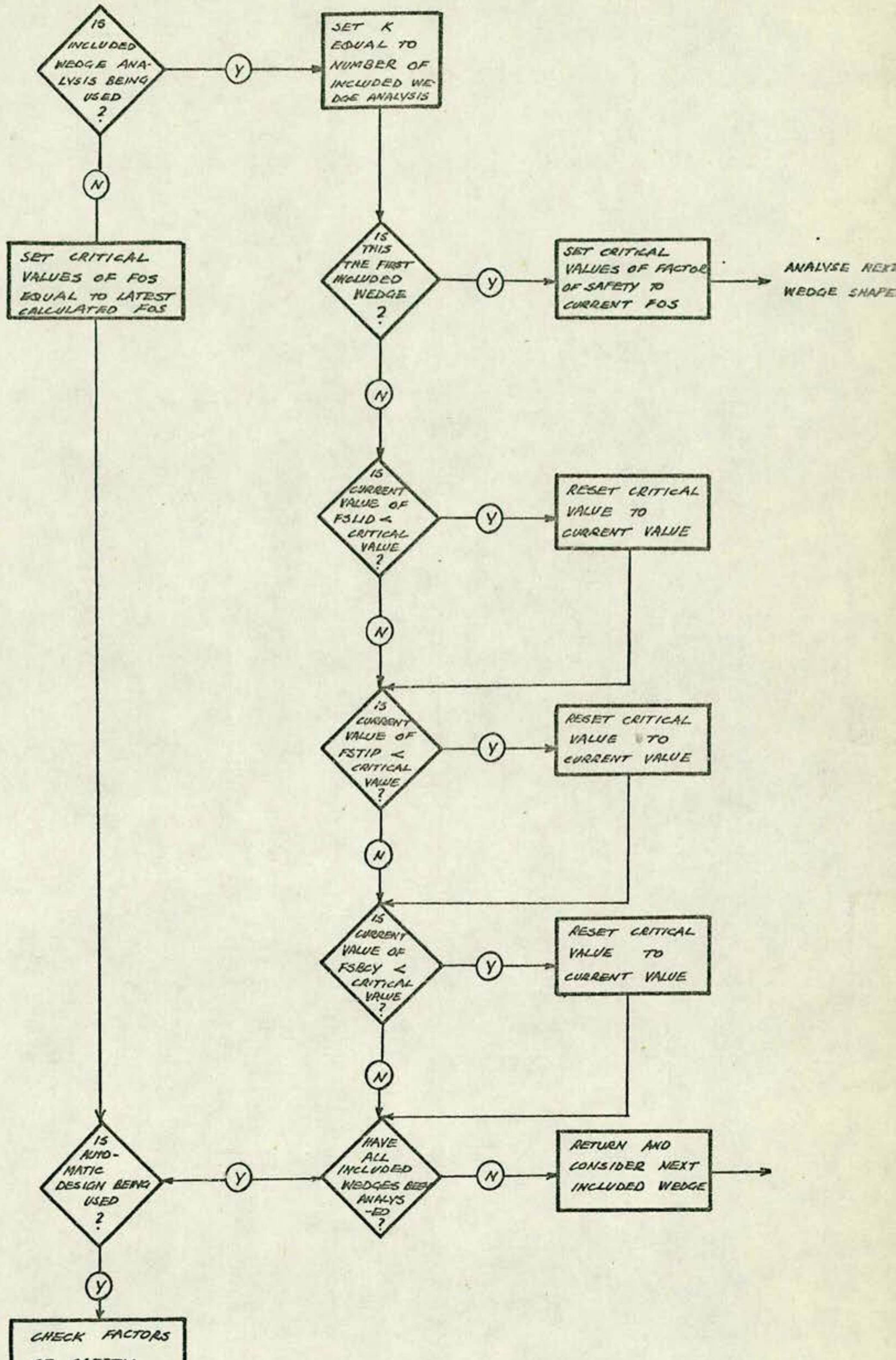


FIG. 5.14.: MANIPULATION OF FACTORS OF SAFETY

When the included wedge analysis procedure is not used the critical values for the factors of safety can be straightaway set equal to the values calculated for the factors of safety.

After all trial wedges have been examined, or in the case of the simple analysis procedure after the critical values are set, a check is made to see if the automatic design procedure is in use. If it is not the program moves straight on to the graphics subroutine SCREEN. When the automatic design method is in use the program moves on to check the critical values, found for the factors of safety, with the design requirements.

5.2.26 Automatic design: check factors of safety

When a cantilever section is being designed automatically it is necessary to check that the factors of safety for the current section are greater than the design requirements before the section can be accepted. (Figure 5.15). If any one factor of safety falls below the design requirement the section is unacceptable. When this occurs the width of the base is increased and, provided the new width does not exceed a certain maximum value, the amended structure is re-analysed. A maximum value is set for the base width to avoid the program ending up in a loop because of some error in data etc.

The maximum base value, BASTOP, is initially set by the program as being equal to the height of soil to be retained. If during the subsequent design the base is increased to a value greater than this maximum the

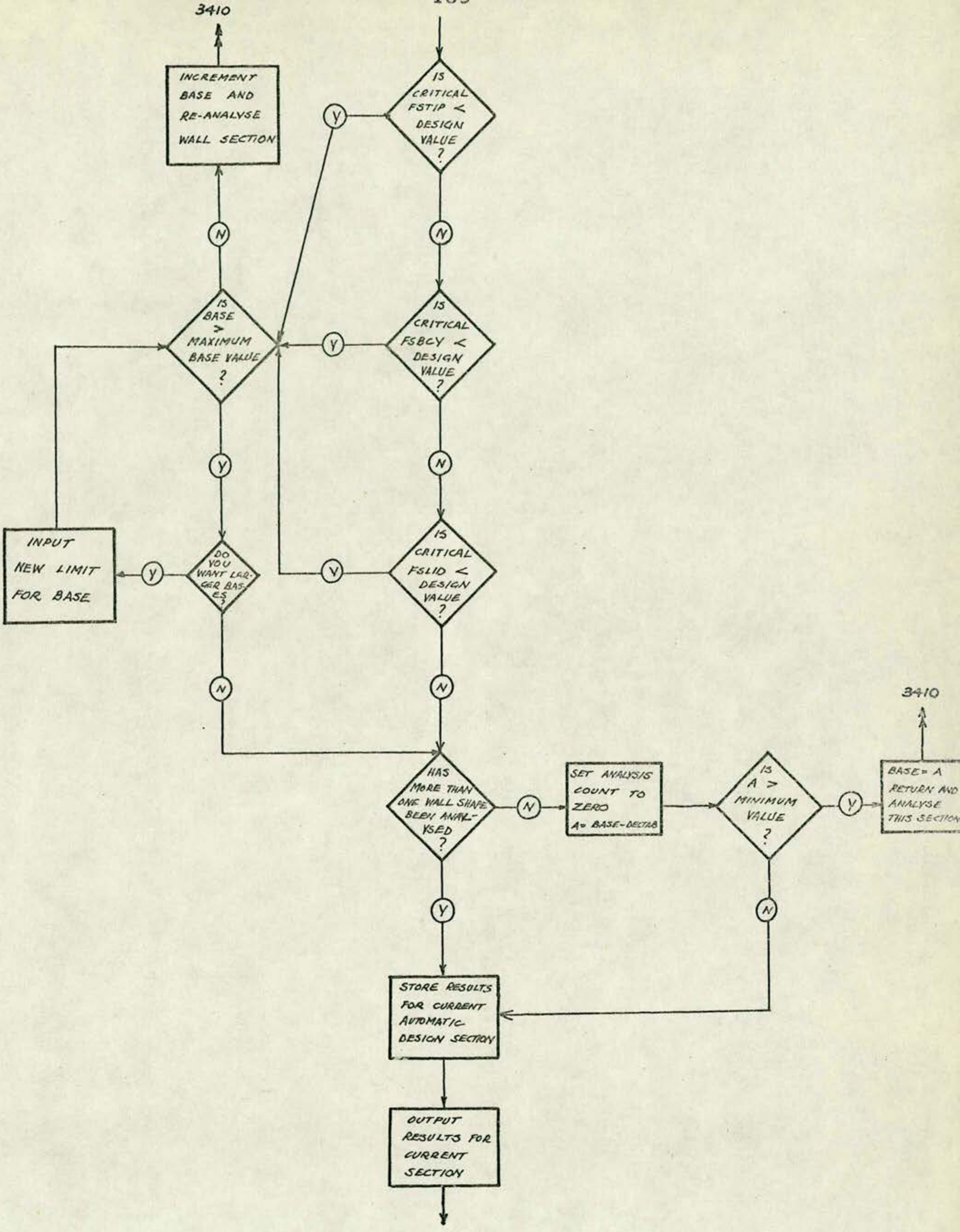


FIG. 5.15. : AUTOMATIC DESIGN CHECK OF FACTORS OF SAFETY

user is informed by the message

BASE WIDTH GREATER THAN WALL HEIGHT :

DO YOU WANT WIDER BASES CONSIDERED?

If the user types Y(yes) then the program will ask for a new maximum value for the base to be set with the message

NEW MAXIMUM VALUE FOR BASE :

The base width will then be incremented and the analysis procedure re-run.

When the designer does not want any further base widths considered the analysis process for this particular section is abandoned although the section does not satisfy the design requirements. The results are stored as for sections that have been found satisfactory and the user will be able to inspect the results later.

When all factors of safety satisfy the design values a check is made to see if more than one wall shape has been analysed. If only one has been examined (NANT = 1) it may be possible to reduce the base width and still have a wall shape that will satisfy the design requirements. If the base width is reduced a check is made to ensure that the base width is not less than the minimum permissible value,BASLOW. (BASLOW has value of either 3.00 ft or 1.00 m). Provided the base value is greater than BASLOW the value of NANT is reset to zero and the new shape analysed. By setting the analysis count to zero this will ensure that if all factors of safety again satisfy the design requirements it will be possible to repeat the base reduction process. If the base reduction process at any time causes the base width to fall below the minimum acceptable value the analysis process is concluded and the program will move on to consider the next toe:base ratio or toe depth as the case may be.

The base reduction process is not used if more than one wall section has previously been analysed, as indicated by an analysis count value (NANT) of greater than unity. When NANT has a value greater than one this indicates that a section analysed has proved unsatisfactoy and the base width had to be increased. In this case the analysis process for this particular section is concluded.

On completion of the design the results are stored in the following arrays:-

RESTP( ) : critical value for factor of safety against overturning

RESSL( ) : critical value for factor of safety against sliding

RESBC( ) : critical value for factor of safety against bearing failure

RESBAS( ) : base width of section

RESRAT( ) : toe:base ratio

RESTD( ) : toe depth

RESWAL( ) : weight of wall

These results can be later output in the form of a table or a graph.

Before returning to consider the next wall shape the results of the design just completed are output on the screen. This will enable the user to follow the rate of progress through an automatic design.

5.2.27 Automatic design: manipulation of results

5.2.27.1 Fix value of BSTART

Before considering the current position of the automatic design procedure the starting value for the base width is adjusted. Initially the user specified the starting base width for the automatic analysis process. This width may or may not be close to the final base width required to meet the design requirements. However for all subsequent analyses the program will set its own starting value for the base width, BSTART. This value is taken as one base increment less than the satisfactory base width found for the previously completed section.

5.2.27.2 Ascertain position of automatic design procedure

Having set the value for BSTART the program will move on to consider the next toe:base ratio for the wall. If however all the required ratios have been analysed for the particular toe depth (NORAT = NRATIO) the program will calculate the minimum base value that has been found for the current toe depth. This is stored in the array BASELO( ) and will be later available for a graph of base width against toe depth. The program also keeps a record of the smallest and largest base widths (BASMN and BASMX). This will be needed to select a suitable scale for plotting the graph.

When all the toe depths requested by the user have been considered (NOTOE = NTOED) the program will go into the graphics routine for output of results. If further toe depths have to be analysed the program will return and consider these.

5.2.28 Graphics subroutine

The majority of the graphics and user interaction facilities are contained in the routine SCREEN.
On completion of the manual or automatic analysis procedures control transfers to this routine.

On return from the graphics routine a check is made to see if the XXXIT, RERUN or GO flags have been set.
If any have been set the program will move to the appropriate statement number.

If no flags are set the program presumes that a re-analysis has been requested and returns to repeat the analysis process used before.

5.2.29 End of program

Selection of the exit option during the interaction procdss will cause the XXXIT flag to be set and the graphics subroutine to return to the main program.
When the XXXIT flag is found in the main program the message

*** PROGRAM END ***

is output, and the terminal is returned to monitor level.

5.3 PROGRAM SUBROUTINES

5.3.1 Subroutine AQUA

For each part of the wall back the co-ordinates of the top (XWT, YWT) and bottom (XWB, YWB) points of intersection of the water with the wall are input to the routine. The routine will then calculate from the standing water level, WATER, the distribution of the water pressure over the part of the wall back under consideration.

The subroutine will return with the water force as PW, the point of application of this force as (XPW, YPW) and the angle of application as APW. A complete list of the variables used in this subroutine is given in Figure 5.16.

5.3.2 Subroutine BORDER

This routine contains the instructions for drawing the surround shown in Figure 4.21.

The date is found using the Fortran library subroutine DATE. The date is in the form dd - mmm - yy and is stored as two words in the array IDATE(2).

5.3.3 Subroutine COG

This subroutine is used in conjunction with subroutine WEIGHT to calculate the area, centre of gravity and moment about the origin of vertical sided strips.

Six co-ordinates are needed to define each strip as shown in Figure 5.18 a flow diagram illustrating the procedure in the subroutine is shown in Figure 5.17.

The program first calculates the area moment for the rectangle enclosing the strip. The moment of the strip is then found by subtracting the moments of the top and bottom triangles.

A flow diagram illustrating the procedure is given in Figure 5.17. A list of the variables used in the routine is given in Figure 5.19 and the majority of these terms as shown on the typical strip in Figure 5.18.

ALEN : length of wall back over which water pressure acts

ANGLE : angle wall back makes with horizontal

APW : angle of resultant water pressure with vertical

PW : resultant water force

PWB : water pressure at bottom of wall section

PWT : water pressure at top of wall section

XW : x-co-ordinate of point of application of resultant water force

XWB : x-co-ordinate of top level of water for present wall element

XWT : x-co-ordinate of bottom level of water for present wall element

YW : y-co-ordinate of point of application of resultant water force

YWB : y-co-ordinate of bottom level of water for present wall element

YWT : y-co-ordinate of top level of water for present wall element

Figure 5.16 : NOMENCLATURE FOR SUBROUTINE AQUA

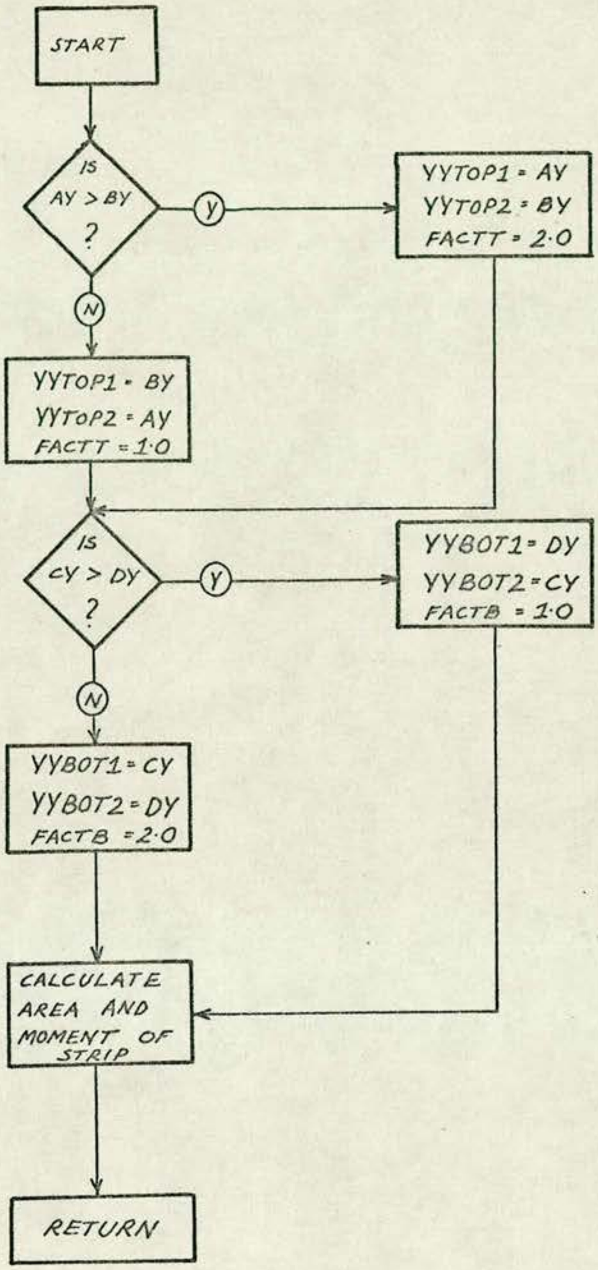


FIG. 5.17 : FLOW DIAGRAM FOR SUBROUTINE COG

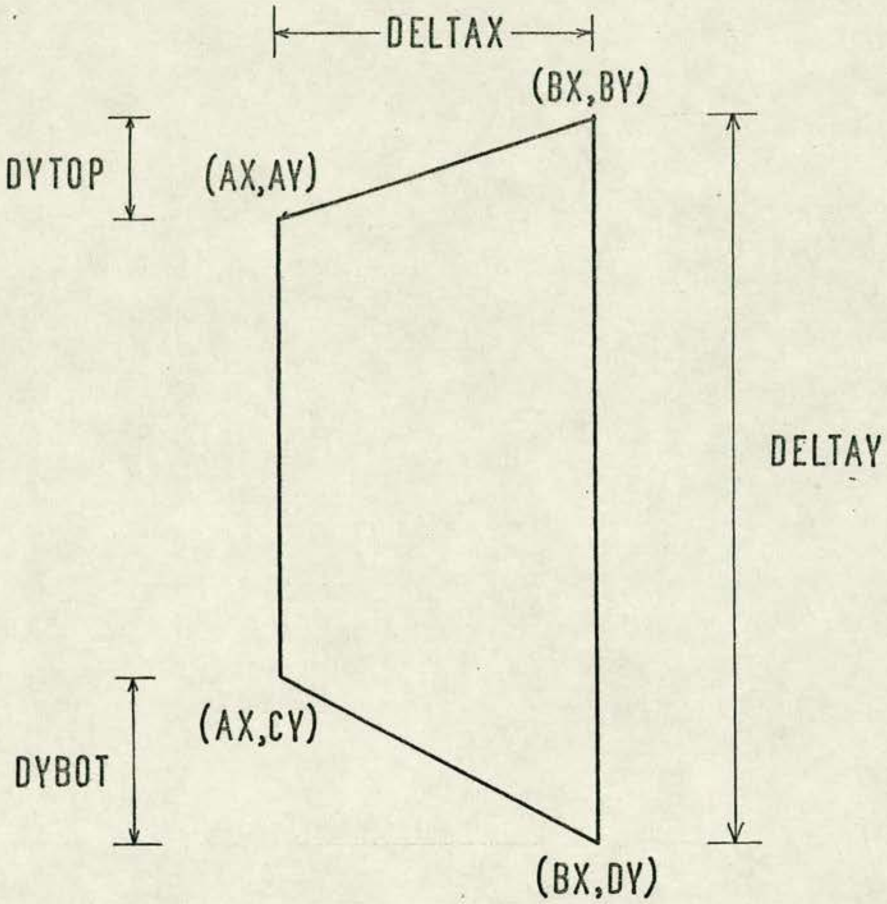


FIG. 5.18. : TYPICAL STRIP FOR SUBROUTINE COG

AMMTY : Area moment of strip about y-axis

AREA : area of strip

AY : y-co-ordinate of top of L.H.S. of strip

BY : y-co-ordinate of top of R.H.S. of strip

CORRN : correction to moment of rectangular wedge to give moment for true wedge shape

CY : y-co-ordinate of bottom of L.H.S. of strip

DELTAX : width of strip

DELTAY : overall height of strip

DY : y-co-ordinate of bottom of R.H.S. of strip

DYBOT : height of bottom of strip

DYTOP : height of top of strip

FACTB : factor for lever arm of bottom triangle

FACTT : factor for lever arm of top triangle

YYBOT1 : y-co-ordinate of lower bottom point

YYBOT2 : y-co-ordinate of higher bottom point

YYTOP1 : y-co-ordinate of higher top point

YYTOP2 : y-co-ordinate of lower top point

Figure 5.19 : NOMENCLATURE FOR SUBROUTINE COG

5.3.4 Subroutine CRACKS

The main program calculates the intersection point of the wedge base with the backfill surface. However when the backfill material is cohesive allowance must be made for the development of a tension crack between the ground surface and the assumed failure surface. Subroutine CRACKS will amend the point found by the main program to make allowance for the tension crack.

The procedure is relatively straightforward and is summarized in Figure 5.20. The nomenclature used in the routine is listed in Figure 5.21 and illustrated in Figure 5.22.

A record of both the point of intersection (XSUR, YSUR) and number of the surface element on which the point was found (IA) is transferred to the subroutine. The subroutine will work back from this element and find the point at which the vertical tension crack fits in between the surface and the trial failure surface. This is done by establishing the equations of the surface elements and the failure surface and then finding the x-co-ordinate of the point that will give a vertical distance between the lines of + HO , the depth of tension crack. The calculated x-co-ordinate is then checked to see if it lies within the limits of the current surface element. When it does the analysis is complete and the routine can return. If this condition is not met the routine will move back and consider the preceeding surface element.

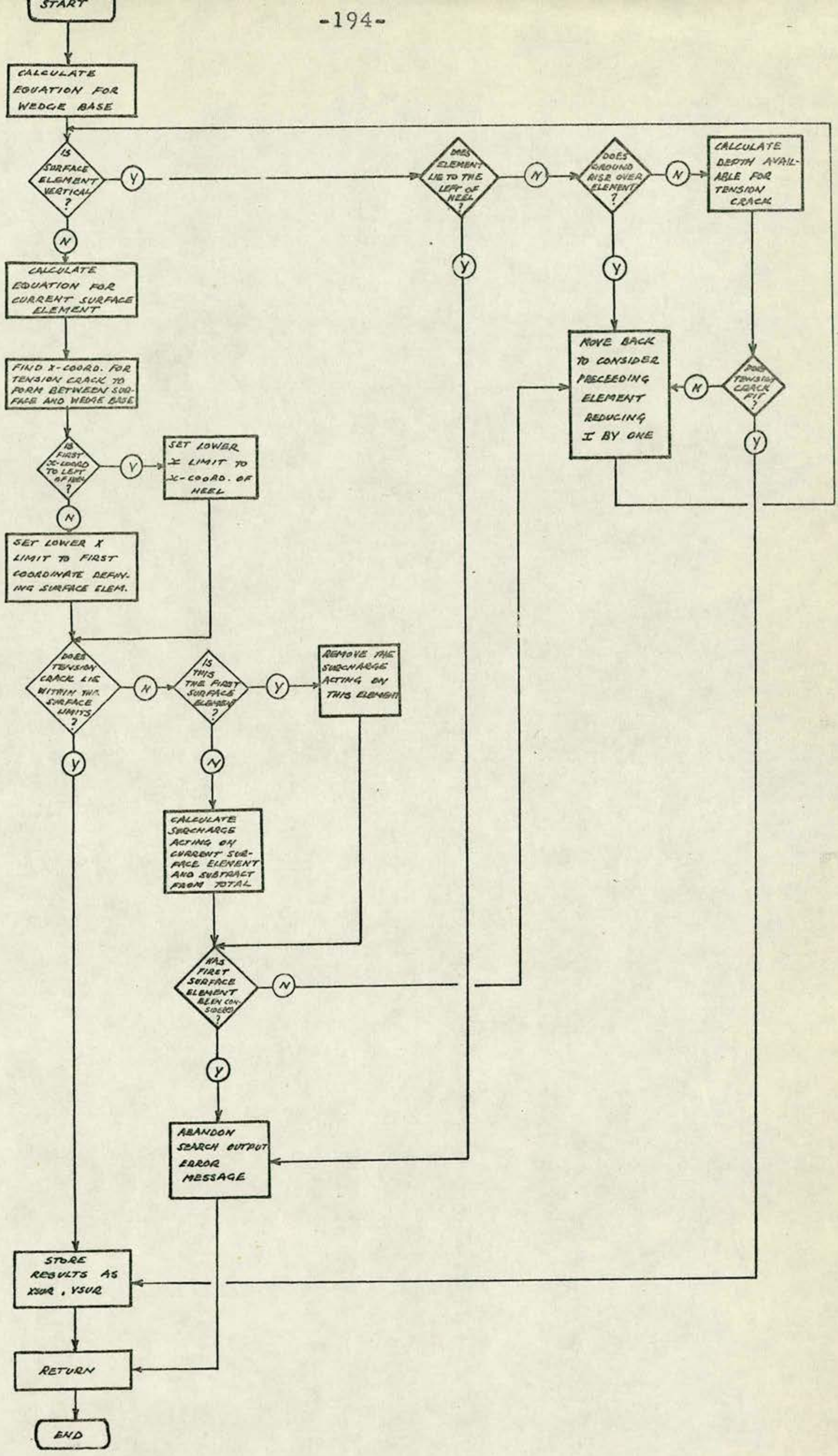


FIG. 5.20.: FLOW DIAGRAM FOR SUBROUTINE CRACKS

AMB : slope of trial failure surface

AMT : slope of current surface element

CBOT : constant term in equation for trial failure surface

CT : constant term in equation for current surface element

CTRLSU : control flag set if more than one surface element need be considered in search for position of tension crack

DELTAW : total surcharge acting on surface element intersected by original failure surface (Figure 5.22)

I : number of current surface element being analysed

IA : number of surface element intersected by failure surface as found in main program

JEND : number of surface element intersected by failure surface after allowance for tension crack

SURWT : total surcharge weight acting above failure wedge

XLOWER : lower limiting value for acceptable x-co-ordinate for position of tension crack for the current surface element

XSUR : x-co-ordinate of intersection of failure surface with ground surface

YSUR : y-co-ordinate of intersection of failure surface with ground surface

WDASH : surcharge acting on the element intersected by original failure surface but not lying above failure wedge (Figure 5.22)

Figure 5.21 : ANNOTATION FOR SUBROUTINE CRACKS

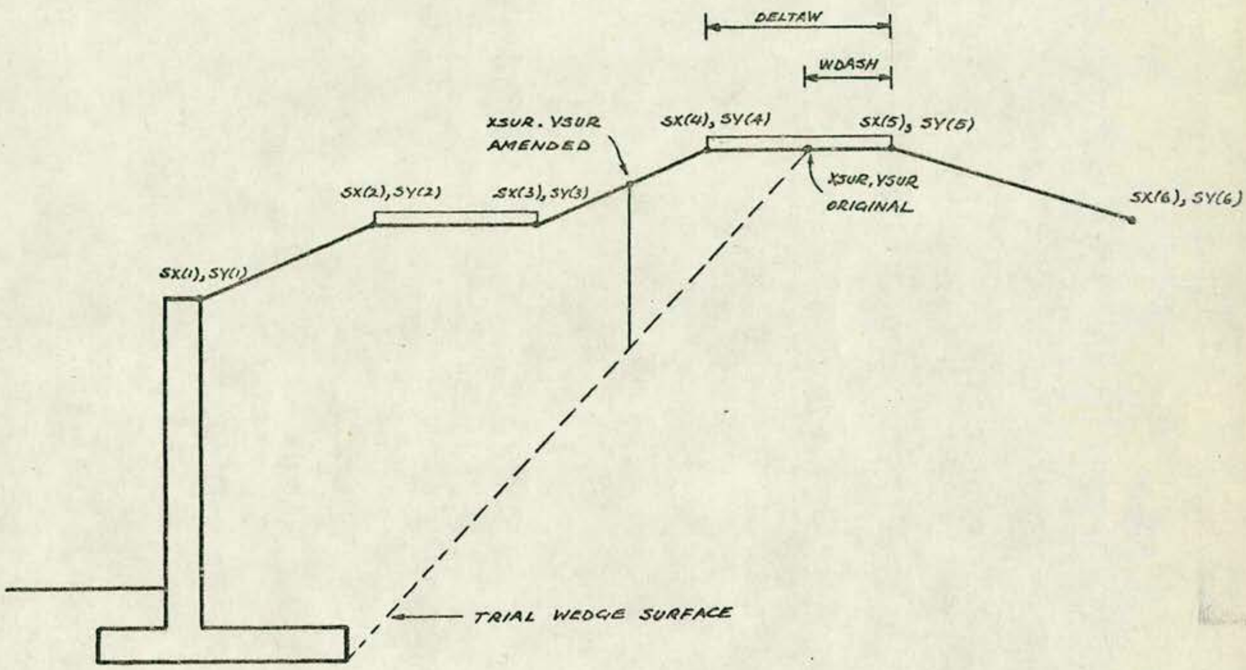


FIG. 5.22. : AMENDMENT OF FAILURE WEDGE TO INCLUDE TENSION CRACK

This process is repeated until the position of the tension crack is found. Throughout the analysis the total surcharge weight acting above the failure wedge is kept up-dated as necessary.

5.3.5 Subroutine DATOUT

This routine simply contains all the graphics instructions for forming the display file for the output shown in Figure 4.7.

5.3.6 Subroutine DATACH

This routine contains the interaction facilities to permit changes to be made to the basic program data. The procedure is summarized in Figure 5.23.

Data changes are made by selection from a menu (Figure 4.8) and to facilitate the process the data terms are not changed directly but through a basic data array which contains all the basic data terms, BASIC( ).

To change a term in the list the user aligns the horizontal cross-hair with the term to be changed and types any keyboard character. The Sturgeon routine IPOSN is then used to find which item in the menu has been selected. Once the item has been identified it's current value is accessed directly from the BASIC( ) array and output on the screen. The user can then insert the new value required. In order to permit the new value to be placed beside the existing value the echo is switched off while the user inputs the up-dated value. Once the input of the new value is complete (after carriage return has been typed) a MOVETO and RLDISP command is used to output the new value along side the old value.

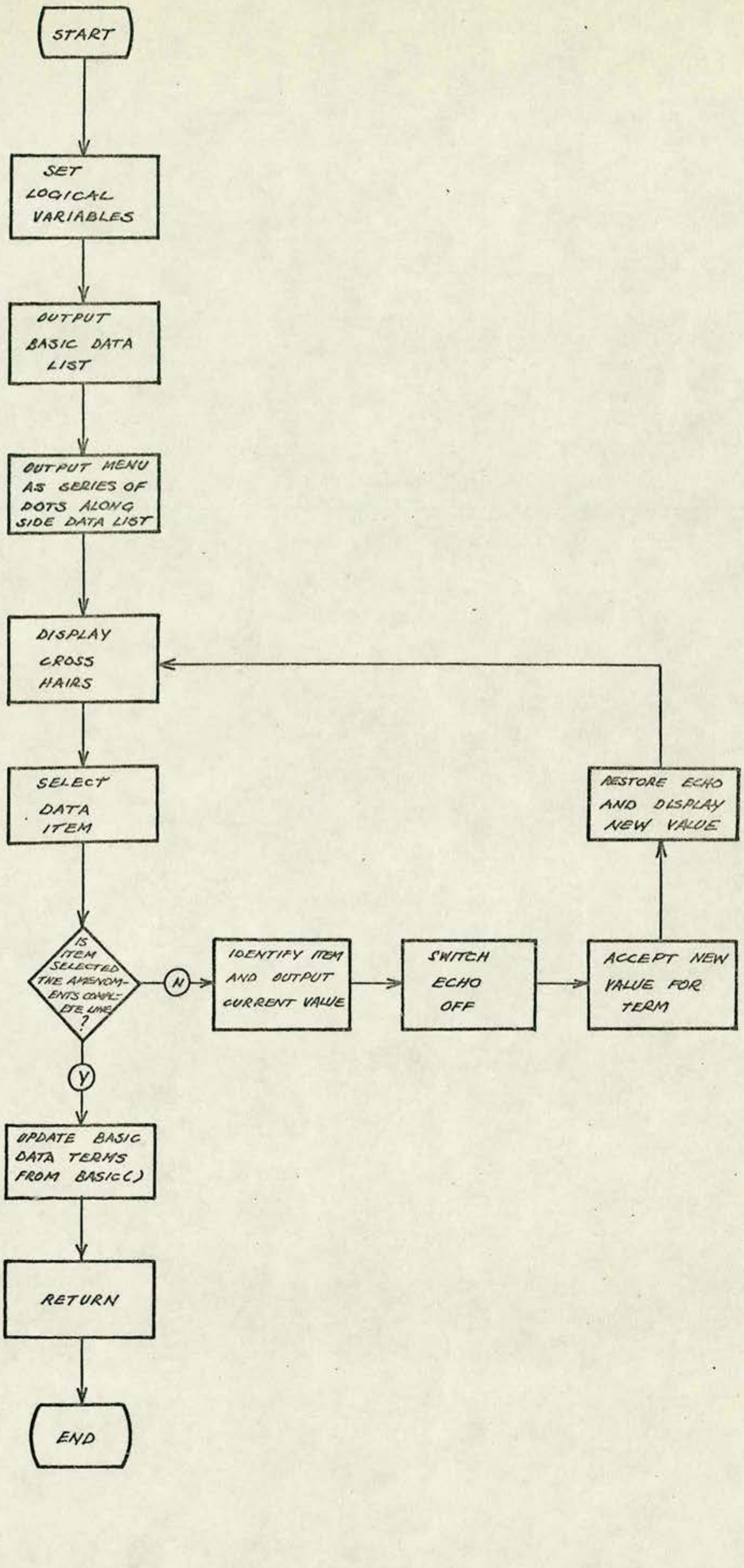


FIG. 5.23. : FLOW DIAGRAM FOR SUBROUTINE DATACH

Up to eight data terms can be changed at any one time. Any attempt to change more than eight terms causes loss of display because of some Sturgeon "funny".

On completion of the data changes all the basic data terms are up-dated from the values in the BASIC( ) array irrespective of whether they have been amended or not.

5.3.7 Subroutine FRICLE

5.3.7.1 Introduction

This subroutine is used to calculate the passive pressure in front of the wall when the wall surface is plane between the toe and the front ground level. The Friction Circle Method is used.

A summary of terms used in the subroutine is given in Figures 5.24 and 5.25. A flow diagram for the subroutine is given in Figure 5.26.

5.3.7.2 Stage (1): Set constants for analysis

Terms which do not vary with the position of the circle centre are established straightaway. Any adhesive force between the soil and the front of the wall will be constant irrespective of the shape of failure surface in front of the wall. This force is stored as ADHESN and is calculated at this stage.

5.3.7.3 Stage (2): Establish line on which circle centre lies

The position of the circle centre is varied by steadily increasing the length XD1. The initial value of XD1 is very small and it is therefore necessary to check that it is feasible to draw circle through point B and the toe of the

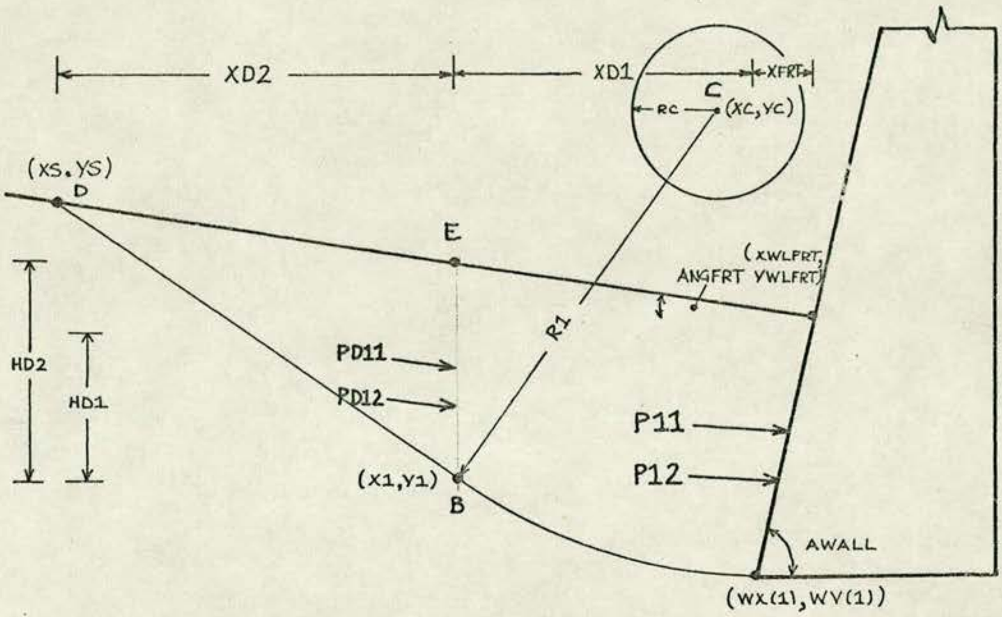


FIG. 5.24. : FRICTION CIRCLE CALCULATION OF PASSIVE PRESSURE

Figure 5.25: NOMENCLATURE FOR SUBROUTINE FRICLE

ADHESN	:	adhesion force between front of wall and soil
AKP	:	Rankine's coefficient of passive pressure
ALR	:	magnitude of resultant after call to RESOLV
ANGCHN	:	angle cohesive force makes with the horizontal
ANGF11	:	angle of resultant on wedge base neglecting soil weight
ANGF12	:	angle of resultant on wedge base neglecting cohesion and surcharge
ANGPD1	:	angle of Rankine force on EB due to cohesion and surcharge
ANGP11	:	angle of passive force on wall due to cohesion and surcharge
ANGP12	:	angle of passive force on wall due to soil weight
ANGR	:	angle of resultant after call to RESOLV
APASE	:	angle of resultant passive force on wall
AWALL	:	angle of front of wall
CB	:	cohesive strength of soil
COHESN	:	resultant cohesive force along curved part of slip surface
COSFRT	:	cosine of angle of slope of ground in front of wall
DELXD1	:	incremental value for increase in XD1
E	:	angle EBD as shown in Figure 5.24
E1	:	angle BDE as shown in Figure 5.24
HD1	:	vertical distance from point B to horizontal through intersection of soil with wall front
HD2	:	vertical distance from point B to ground surface
HWALL	:	vertical distance from toe to intersection of ground and wall front

PASIVE	:	minimum passive force on front of wall
PD11	:	Rankine passive force on EB due to cohesion and surcharge
PD12	:	Rankine passive force on EB due to soil weight
P11	:	passive force on wall due to cohesion and surcharge
P12	:	passive force on wall due to soil weight
PPQ	:	resultant passive force on front of wall
QFRONT	:	surcharge on soil in front of wall
R1	:	radius of circular part of slip surface
RC	:	radius of friction circle
SAVEPP	:	lowest value of resultant passive pressure found so far
SAVPP1	:	lowest value of passive pressure due to cohesion and surcharge
SAVPP2	:	lowest value of passive pressure due to soil weight
SURL	:	length DE on Figure 5.24
TANFRT	:	tangent of angle of slope of ground in front of wall
W1	:	weight of soil wedge above curved portion of failure surface
XC	:	x-co-ordinate of circle centre
XCS1	:	x-co-ordinate of point on line of action of cohesion force
XD1	:	horizontal distance from toe of limit of curved portion of slip surface
XD2	:	horizontal distance ED on Figure 5.24

XF11 : x-co-ordinate of point through which F11 acts

XF12 : x-co-ordinate of point through which F12 acts

XPASE : x-co-ordinate of resultant passive pressure on wall

XP11 : x-co-ordinate of passive force on wall due to cohesion and surcharge

XP12 : x-co-ordinate of passive force on wall due to soil weight

XR : x-co-ordinate of point through which resultant passes on return from RESOLV

XS : x-co-ordinate of intersection of slip surface and ground

YC : y-co-ordinate of circle centre

YCS1 : y-co-ordinate on line of action of cohesion force

YD2 : vertical difference between point D and E Fig 5.24

YF11 : y-co-ordinate of point through which F11 acts

YF12 : y-co-ordinate of point through which F12 acts

YPASE : y-co-ordinate of point of application of resultant passive force on wall

YP11 : y-co-ordinate of point of application of P11

YP12 : y-co-ordinate of point of application of P12

YR : y-co-ordinate of point through which resultant passes on return from RESOLV

YS : y-co-ordinate of intersection of slip surface with ground

Y1T : y-co-ordinate of point E Figure 5.24

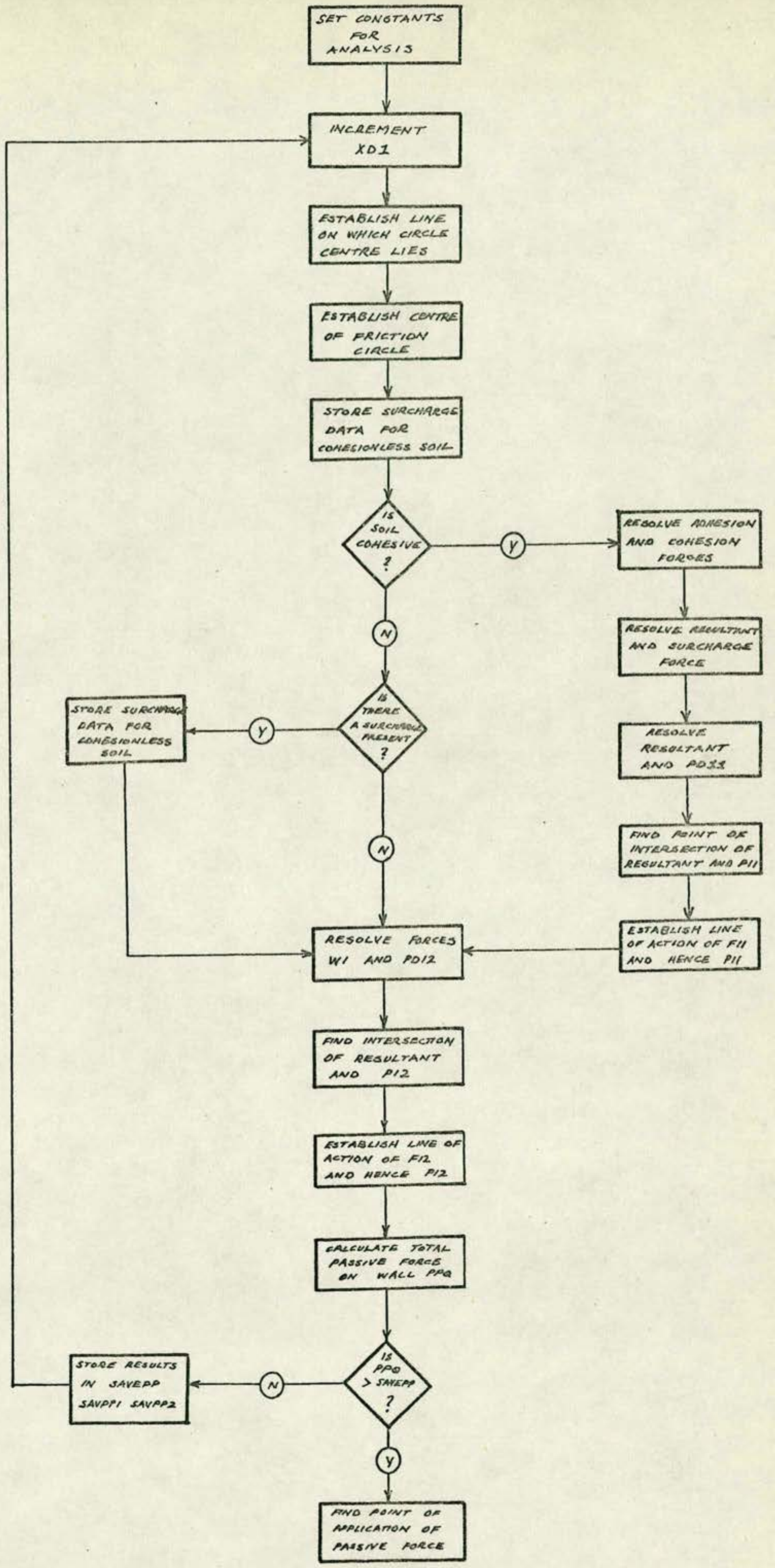


FIG. 5.26. : FLOW DIAGRAM FOR FRICTION CIRCLE METHOD

wall given that the circle centre must lie on line BC.

This is checked by calculating the point of intersection of a line normal to BC with the line of the front of the wall. (This is equivalent to considering a circle with centre on BC with infinite radius.) If the intersection lies above the toe of the wall it will not be possible to find a satisfactory circular surface. In such a case the value of XD1 should be increased.

5.3.7.4 Stage (3): Establish centre of friction circle

The centre of the circle is selected to lie on BC in such a position that an arc can be drawn to pass through point B and the toe of the wall.

5.3.7.5 Stage (4): Store surcharge data for cohesionless soil

If soil is cohesionless and there is surcharge acting on ground in front of wall it is necessary to store relevant information about the surcharge force in XR, YR, ALR, ANGR, SIGNR so that it is ready for resolution at stage (7).

5.3.7.6 Stage (5): Resolve adhesion and cohesion forces

The first step when dealing with a cohesive backfill is to establish the resultant of the adhesive force along the front of the wall ADHESN, and the cohesive force along the circular part of the base, COHESN.

The magnitude, direction etc. of the adhesive force is constant for all shapes of failure surface and this was established therefore at stage (1).

5.3.7.7 Stage (6): Resolve resultant and surcharge force

The weight and line of action of any surcharge load acting above curved portion of wedge is determined. This force is then resolved with the resultant found at stage (5).

5.3.7.8 Stage (7): Resolve resultant and PD11

PD11 is the Rankine passive force on EB due to consideration of just surcharge and cohesion. The distribution of the passive pressure due to these two is uniform and the resultant force on EB acts parallel to the ground surface and half way up EB.

PD11 is calculated and resolved with the resultant from stage (6).

5.3.7.9 Stage (8): Find point of intersection of resultant and P11

Before the magnitude of the passive force on the wall due to surcharge and cohesion (P11) can be found it is necessary to discover the line of action of the resultant force on the wedge base F11.

It is known that F11 will pass through intersection of resultant and P11 and be tangential to friction circle.

As yet the magnitude of P11 is unknown, however its line of action and point of application are known. At this stage P11 is given a dummy value of 10.00 and subroutine RESOLV used to find the intersection point of P11 and resultant from stage (7).

5.3.7.10 Stage (9): Establish line of action of F11 and hence magnitude of P11

The line of action of the resultant on the base is determined by call to subroutine TANGNT. The sine rule can then be used to calculate the magnitude of P11.

5.3.7.11 Stage (10): Resolve forces W1 and PD12

This is the first stage of the second part of the analysis. Surcharge and cohesion forces are now neglected and the passive force on the wall due to the weight of soil is calculated.

The weight of soil above the curved portion of the wedge (W1) is calculated and resolved with the Rankine passive force (due to soil weight) on EB, PD12.

5.3.7.12 Stage (11): Find point of intersection of resultant and P12

Before the magnitude of the passive force on the wall due to soil weight (P12) can be found it is necessary to discover the line of action of the resultant force on the wedge base, F12. F12 will pass through intersection point of resultant from stage (10) and force P12.

The magnitude of P12 is as yet unknown however we do know it's point of application and line of action. It will be given a dummy magnitude of 10.00 so that RESOLV can be used to find the intersection point.

5.3.7.13 Stage (12): Establish line of action of F12 and hence magnitude of P12

The line of action of F12 is ascertained by a call to subroutine TANGNT. The sine rule can then be used to find P12.

Having calculated P12 the total passive force on the wall is known. A check is now made on the new value of the passive force. If it is found to be less than the previous value the analysis is continued and a new failure surface considered. If the current value is found to be greater than the previous one the analysis is concluded and the stored value taken as the passive force on the wall.

5.3.7.14 Stage (13): Find point of application of passive force

The point of application of the resultant passive force on the front of the wall is found by taking moments about the toe.

5.3.8 Subroutine GRAPH

Subroutine GRAPH is used to draw the graphs of both base against toe depth and base against toe:base ratio.

The routine requires the following data:-

(i) origin for the graph: IXO, IYO

(ii) co-ordinates for points to be displayed: IPTX( ), IPTY( )

(iii) scale increments for axes: XSCALE( ), YSCALE( )

(iv) number of scale increments for each axis: NX, NY

(v) scale factor for drawing graph: FACTOR

(vi) increments for scaling axes: INCRX, INCRY

(vii) Flag indicating which graph is to be drawn: GRAPH1

The procedure for drawing and labelling the axes, and drawing the graph is straightforward graphics and requires no explanation.

5.3.9 Subroutine KEYS

As already discussed in chapter 3 provision is made in the program for the inclusion of a heel key in the wall design.

A key can be introduced at three stages during the running of the program. On each occasion input of the key dimensions is accomplished by a call to subroutine KEYS. This subroutine contains the necessary prompts and interactive input commands to permit the designer to specify the depth and width of base key required.

5.3.10 Subroutine PAPA

As discussed in chapter 3, section 3.2.3.2 the active force is calculated at various points down the back of the wall. This permits the numeric differentiation technique to be used to establish the point of application of the resultant active force. This routine carries out the numeric differentiation process.

Before the pressure distribution can be considered the array ACTIVE( ) has to be rearranged so that the first entry in the array refers to the active pressure of the top of the wall and has a value of zero.

When the wall back is broken the resultant active pressure is considered in two parts PATOP and PABOT. For plane backed surfaces only PATOP is calculated.

The point of application of the resultant force or forces is found by calculating the active force acting on each element of the wall back (Figure 5.27). These forces are assumed to act at the mid-point of the wall elements. Moments are then taken of each elemental force about the bottom of that part of the wall. The point of application of the force is found by dividing the sum of the moments by the total resultant force on that part of the wall. The points of application are stored as XPATOP, YPATOP and XPABOT, YPABOT. The y-co-ordinates are not relative to the origin but represent the height above the toe at which the forces act.

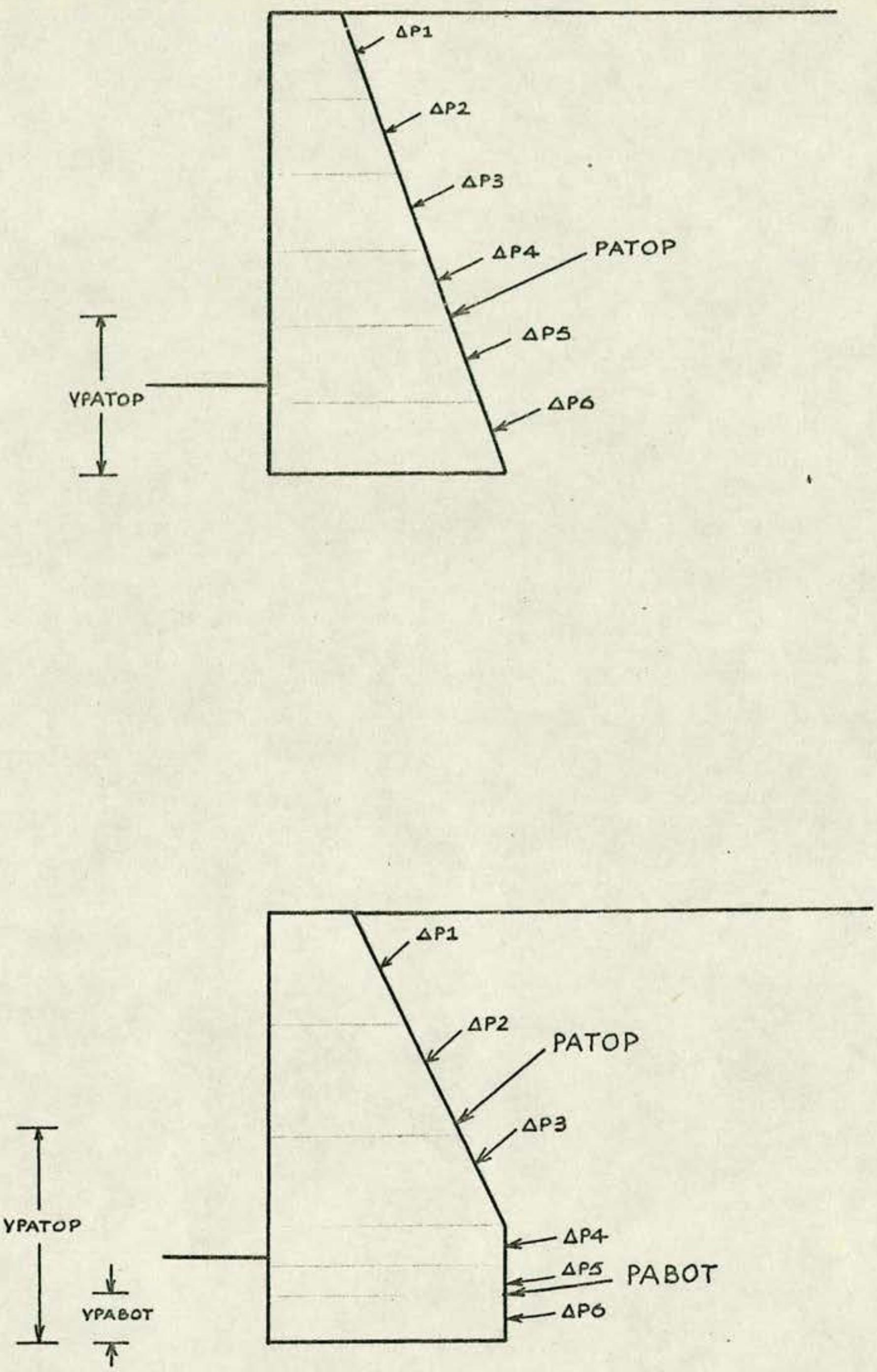


FIG. 5.27. : CALCULATION OF POINT OF APPLICATION OF ACTIVE FORCES

5.3.11 Subroutine RESOLV

As the name suggests this subroutine is used for finding the resultant of two forces. The routine is used exclusively by subroutine FRICLE.

Five parameters are required to describe each force:-

(i) x-co-ordinate of a point through which the forces act (X1, X2)

(ii) y-co-ordinate of a point through which the forces act (Y1, Y2)

(iii) magnitude of the forces (AL1, AL2)

(iv) sign of the forces: this is used to indicate in which direction along the line of action the force acts. Forces are assumed positive if x-co-ordinates increase along the line of action. Vertical forces are positive if they act upwards (SIGN1, SIGN2)

(v) the angles the lines of action make with the horizontal (ANG1, ANG2)

Given this data for each force subroutine RESOLV will calculate the resultant of the two forces. The data relating to the resultant will be stored as XR, YR, ALR, SIGNR, ANGR.

5.3.12 Subroutine SCREEN

5.3.12.1 Introduction

During program development the graphics and user interaction facilities were, where possible, kept separate from the main program and grouped together in a subroutine. This considerably simplified program editing. This structure forms a logical division in the program and is retained in the final version.

The user interaction and graphics facilities offered in this subroutine were discussed in chapter 4. The programming behind the provision of these facilities will be discussed in this section.

A flow diagram outlining the overall operation of the subroutine is shown in Figure 5.28.

5.3.12.2 Set logical variables to initial values

Logical variables are generally used as control flags for the program. There are two exceptions LOG and LOGF. These terms are synonymous with the logical terms .TRUE. and .FALSE. As has been already explained LOG and LOGF are used in certain STURGEON commands because of machine difficulty in recognising .TRUE. and .FALSE. as a result of a software problem.

The following logical variables are used in this subroutine:-

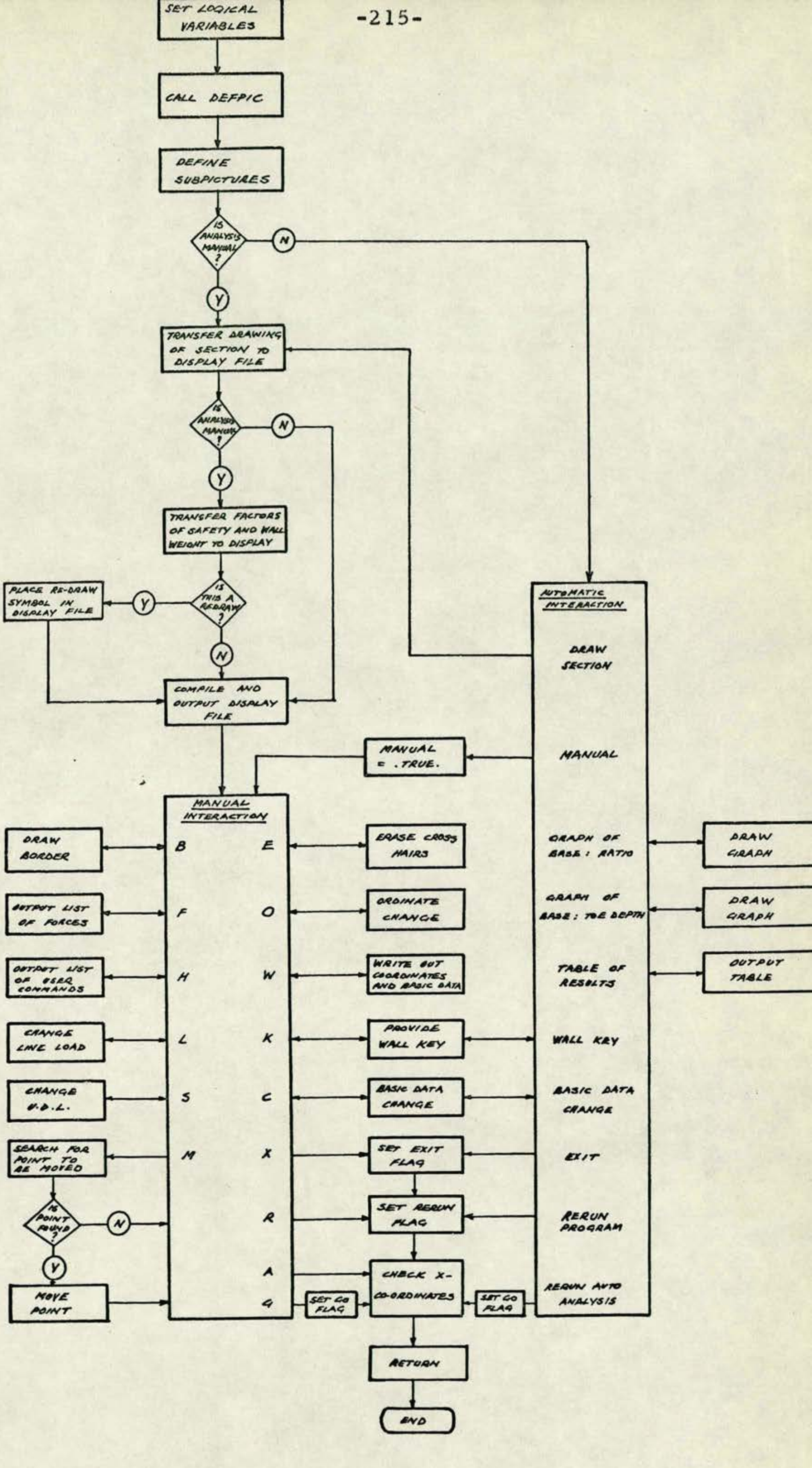


FIG. 5.28. : FLOW DIAGRAM FOR SUBROUTINE SCREEN

(i) GRAPH1:

When graphs of base against toe:base ratio are to be output this flag is set and will ensure that the horizontal axis of each graph is labelled.

(ii) RDRAW:

When a redraw has been requested this flag is set and will cause a large R to be output on the screen when the section is redrawn. This is to remind the designer that a redraw has taken place and that the displayed factors of safety do not refer to the section currently displayed on the screen.

(iii) GO:

When the analysis process is to be re-run this flag is set and will ensure that on return to the main program the program will return to the beginning of the analysis process.

(iv) RERUN:

Similar to the GO flag but set when the program is to be re-run right from the start.

(v) OVER:

There will seldom be enough screen area available to permit the display of the complete backfill surface. Attempts to draw the complete surface will generally result in an edge violation. When this condition is found to be imminent flag OVER is set. The program will then reduce the amount of the current element that is output to fit the available screen area and will conclude the surface drawing at this stage.

(vi) XXXIT:

The exit flag XXXIT is set when the designer has decided to exit from the program. This ensures that on return to the main program the program will proceed to the END statement.

5.3.12.3 Definition of subpictures

Subpictures and graphics subroutines and are used in a similar manner to normal subroutines. Once defined they can be called at any time during the program and cause an instance of whatever is in the subpicture to be inserted in the current segment of the display file.

Five subpictures are used:-

(i) Subpicture IRAR:

contains instructions used for drawing the letter R. This symbol is output on the screen to remind the user when a redraw of the wall shape has occurred.

(ii) Subpicture IMARK:

contains instructions for drawing an upward arrow. This symbol is used to mark the position of the resultant on the base of the wall.

(iii) Subpicture ICROSS:

contains instructions for drawing a small diagonal cross. The cross is used to mark the co-ordinate points on the wall section.

(iv) Subpicture IDOT:

contains instructions for drawing a dot. The dot is used to mark the co-ordinate points on the backfill surface and although invisible to the user it can be defined as a segment and can therefore be identified by the cross-hairs.

(v) Subpicture IARROW:

contains instructions for drawing a downward pointing arrow. This symbol is used to indicate line loads on the backfill surface.

If the program has been run in automatic mode two further subpictures are required:-

(i) IVERT:

small vertical line used to scale horizontal axis when drawing a graph.

(ii) IHORZ:

small horizontal line used to scale vertical axis when drawing a graph.

5.3.12.4 Automatic analysis: user interaction

User interaction after automatic analysis is accomplished by menu selection. The list of options has already been discussed in chapter 4, section 4.4.9.

5.3.12.5 Automatic analysis: graph of base against toe depth

Five main stages can be identified in the procedure for drawing the graph:-

(i) Label x-axis and form x-co-ordinates:

The values for labelling the horizontal axis are stored in the array XSCALE( ). The x-co-ordinates of points to be output on the graph are stored in the array IPTX( ). These co-ordinates all refer to the screen co-ordinate system.

(ii) Label y-axis and form y-co-ordinates:

The values for labelling the y-axis are stored in YSCALE( ). The y-co-ordinates of points to be plotted are stored as IPTY( ).

(iii) Set other values required by graph:

The origin for this graph will be the point (100,100) and the program variables for this point IXO, IYO are set. The subroutine graph is used to draw the graph and it is written to produce a graph and axes that occupy just under a quarter of the available screen area. This will allow up to four graphs at a time to be output on the screen. Here however only one graph is required therefore by setting FACTOR to 2.00 the scale of the drawing will be doubled thereby producing a graph that will occupy the full screen area.

(iv) Label graph and list ratios considered:
Before calling the graph drawing routine the labels for the axes and the heading for the graph are entered in the display file. A list of the toe:base ratios is also output on the screen and this too is entered in the display file.

(v) Draw graph and display:
The instructions for drawing and scaling the axes and plotting the graph are contained in subroutine GRAPH.
The Sturgeon command CALL DEPICT (IDFILE, 1) causes the display file to be compiled and transmitted to the screen.

5.3.12.6 Automatic results: graph of base against ratio

Four main stages can be identified in the procedure:-

(i) Select scale factor for graph:
Before any preparation is made for drawing the graph a check is made to ensure that a graph can be plotted. i.e. there must have

been more than one toe:base ratio considered. When a graph cannot be drawn the user is informed by the message 'ONLY ONE RATIO CONSIDERED: GRAPH CANNOT BE DRAWN' and the program returns to the user interaction stage. When a graph can be drawn the scale factor for the graph is set initially to 1.00. This will permit up to four graphs to be output on the screen at once. If only one toe:base ratio has been considered the scale factor is set to 2.00. This will ensure that the full screen area is used for the graph.

(ii) Label x and y axes:

The labels for the x-axis are obtainable directly from the RATIOS( ) array. This array contains all the values of toe:base ratio used in the analysis stored in sequence.

The labels for the y-axis are worked-out from the overall minimum (OVMIN) and overall maximum (OVMAX) base widths found during the design.

(iii) <u>Establish x and y co-ordinates</u>:

The procedure is slightly more complicated than for the graph of base against toe depth because up to four graphs can now be output simultaneously. The term JG is used to keep a record of how many graphs have been transferred to the display file. A maximum of four graphs can be accommodated on the screen at any one time and JG therefore has a value of between one and four.

The position for the origin of each graph (IXO, IYO) is selected according to the value of JG. Once the origin has been fixed the points for display on the graph can be found. The x-co-ordinates of the points IPTXC( ) are uniformly distributed along the x-axis and are fixed according to the number of ratios considered. The y-co-ordinates are dependent upon the base widths found during the analysis. These have to be retrievedfrom the array RESBAS( ).

(iv) <u>Draw graphs</u>:

Each graph is drawn and transferred to the display file by the subroutine GRAPH. The graphs are labelled with the toe depth to which they refer. The display file is only output if all graphs to be output have been drawn (J = NTOED) or if four graphs are already stored in the display file (JG = 4).

After output of the display file the program will pause and continue only when the user signifies his readiness by typing any teletype key. A check is then made to see if any further graphs are to be output by comparing the value of J, the number of the latest graph output, with NTOED the number of graphs to be output. If more graphs are to be drawn the drawing procedure is repeated.

After all the graphs have been output the program returns to the user interaction menu.

5.3.12.7 Automatic analysis: table of results

As an alternative to graphical output the results from the automatic analysis procedure can be output in tabular form (Figure 4.17).

The border, output heading and underlining of column headings are all stored in the display file. The terms for insertion in the table are output directly on the screen by means of SENDHS commands.

On completion of the output a dummy call is made to CURSOR. The program will then return to the automatic interaction stage when the user types any keyboard character.

5.3.12.8 Draw wall section and ground profile

(i) Draw wall section:

The scale for drawing the wall section and ground profile, WSCALE, is determined from the height of the wall, and is given by the equation

WSCALE = 400.00/WALL HEIGHT

A separate set of screen co-ordinates corresponding to the wall co-ordinates are formed and stored in the array IXWALL( ), IYWALL( ). Any subsequent alteration to the wall shape is done via these screen co-ordinates with the true wall co-ordinates being amended accordingly.

Drawing the wall section always starts from screen point (200, 150) with the bottom of the toe being positioned here. Each co-ordinate point on the wall section is marked with a cross with each cross being defined as a separate segment of the display file. Each cross is sensitive to cursor identification.

Where a heel key has been incorporated in the design the drawing instructions for it are included in the display file as a separate segment. The shape of the key cannot be changed using the cross-hairs and therefore the co-ordinate points defining it are not marked by crosses.

(ii) Draw backfill surface:

The screen co-ordinates for the points defining the backfill profile are calculated and stored in the arrays ISX( ), ISY( ). When the drawing instructions for the backfill are being transferred to the display file a check is made to ensure that the drawing does not exceed the available screen area. The terms ITOTX and ITOTY are used to keep a record of the position on the screen of the most recent surface co-ordinate during the formation of the drawing instructions for the ground profile. Before each instruction is transferred to the display file a check is made to ensure that ITOTX does not exceed 1020 and ITOTY does not exceed 780. If these limiting values are exceeded an edge violation will occur and to avoid this it is necessary to scale down the amount of the current element that is output, so that it will fit into the available screen area. After such an adjustment the screen edge violation flag OVER is set and this will ensure that no further surface elements are considered for drawing.

After transferring the instructions for drawing each surface element to the display file, a check is made to see if that element has any surcharge acting on it, and if it has whether it is a point or uniformly distributed load. When a uniformly distributed load is present this is shown by drawing another line parallel to the surface element and ten screen units above the ground. This additional line is connected to the ground element at either end by a line at right angles to the surface. If the surface load is a line load this is shown by drawing a downward arrow at that point on the surface. The drawing instructions for the arrow are contained in the subpicture IARROW. The magnitude of both uniformly distributed loads and line loads is indicated by a figure placed above the load.

(iii) Display of ground in front of the wall:
The ground in front of the wall is restricted to a plane surface and the co-ordinates of the point of intersection of the surface with the wall have already been established and stored in (XWLFRT, YWLFRT). The screen co-ordinates for this point are calculated and stored as (IFX, IFY).

(iv) Display of water level behind wall:
When there is a standing water level behind the wall this is shown by a horizontal dashed line. The dashed line is output by going through a loop which contains two line drawing instructions. One draws a solid horizontal line ten units long the other an invisible horizontal line ten units long.

(v) Mark position of base resultant:

The position of the resultant force on the base of the wall was stored as (XBASE, YBASE). The screen co-ordinates of this point are now calculated and the point marked with the upward arrow which is stored in subpicture IMARK.

(vi) Display of factors of safety and wall weight:

Where manual analysis has been used the three factors of safety and wall weight are output along with the cross-section.

If after amending either the section, wall profile or data a re-draw is carried out the latest calculated factors of safety are output along with the amended shape. These factors of safety do not refer to the displayed section but are retained for reference purposes. To avoid confusion the user is reminded that a redraw has taken place by outputting a large R on the right hand side of the screen. The instructions for drawing the R are contained in the subpicture IRAR.

(vii) Complete and depict display file:

Before outputting the display file the screen is cleared by a call to ERASE. After output the program returns to the manual interaction stage and the cross-hairs are displayed on the screen.

5.3.12.9 Manual analysis: user interaction

Manual interaction is carried out exclusively by teletype single letter commands. The commands used have already been discussed (chapter 4, section 4.4.8) The mechanism behind the interaction process is discussed here.

A call to Sturgeon routine CURSOR causes the cross-hairs to appear on the screen. The program will then wait for the user to select the next procedure by typing a teletype character. When a character is struck the ASCII value of the character is stored in the term JC and the co-ordinates of the current position of the cursor stored in ICX and ICY. A series of commands is then used to find which character was struck and to send the program to the appropriate part of the subroutine.

If command M (MOVE) is used to move a wall or ground co-ordinate point, the Sturgeon routine SFIND is used to find which of the currently sensitive display file segments is nearest to the cross-hairs. The system name of the segment is stored in ISN. If no segment lies within a $\frac{1}{4}$" of the cursor the routine will return with ISN = 0 . In such a case the cursor has not been positioned close enough to the point to be identified and the program will simply go back to the start of manual interaction (statement number 883) and the user will have to position the cursor more accurately.

When a point is successfully identified the cross-hairs will move on to the point and another call to CURSOR will be made. The user can now move the cross-hairs to new position for the point. By typing M (MARK) the co-ordinates of the new position will be read-in and stored as ICX, ICY. The screen co-ordinates of the point to be moved IXWALL(INEW), IYWALL(INEW) are given the new values ICX, ICY and the new position marked with a dot.

The real movements of the point corresponding to the screen movements DELTAX and DELTAY are calculated and the resulting amendments are made to the real co-ordinates WX(INEW), WY(INEW).

The procedure for moving a point has been discussed with reference to a wall co-ordinate. Exactly the same procedure is used for a surface co-ordinate. When the user name for the segment (INEW), found after typing the M(MOVE) command, is greater than 100 the point to be moved lies on the backfill surface.

After completion of the co-ordinate move the program returns to the manual user interaction stage.

5.3.12.10 Controlled ordinate change

This procedure can be used for both wall and backfill co-ordinates.

When the user name for the identified segment is greater than 100 the point concerned will lie on the backfill surface. Surface co-ordinates were allocated user names from 101 upwards and the actual point selected has true co-ordinates SX(INEW), SY(INEW) where

INEW = USER NAME - 101

When the user name is less than 100 the segment found refers to one of the points lying on the wall surface and the point can be identified directly as WX(INEW), WY(INEW) where INEW is the user name of the identified segment. The ordinate change is accomplished by two calls to SENDRL with first the x-co-ordinate and then the y-co-ordinate output. After each output the program waits for the user to input the new value for the term.

When the point to be moved is the point defining the first co-ordinate on the ground profile both this point and the wall co-ordinate defining the top of the wall back are amended.

5.3.21.11 <u>Change of surcharge loading</u>

The change of a surcharge loading is straightforward once the load to be changed has been identified. When a line load is to be adjusted there is difficulty in identifying the correct surface co-ordinate. This is because a line load is defined by two surface points both with the same co-ordinates. The correct point is found by comparing the co-ordinates of the point identified SX(I), SY(I) with the co-ordinates of the subsequent point. If the co-ordinates are identical the correct point has been found. If they are not identical the point must be the second point defining the position of the line load in which case the value of I must be reduced by one.

When a surcharge loading starts right from the wall back a wall co-ordinate may be identified instead of the first surface co-ordinate. This error is avoided by checking the value of the user name for the segment identified. If the user name is less than 100 a wall ordinate has been found, in which case the point to be identified is taken as the first surface co-ordinate and the value of I set to one.

Having identified the correct surface point the current value for surcharge, SURCH(I), is output and the program waits for the new value to be input.

5.3.12.12 Output force details

A list of the earth and water forces is output using the normal Fortran TYPE command.

Graphics commands are used to underline the column headings (Figure 4.20) and an automatic call to BORDER is made to provide a surround for the display. The display is headed FORCE DETAILS.

5.3.12.13 Data change

The data change procedure is held in subroutine DATACH and has already been described in section 5.2.5. On completion of the changes the program will return to either the manual or automatic interaction stage depending upon which design approach is in use.

5.3.12.14 Output co-ordinates and soil properties

A drawing of the wall section is in itself of little use unless accompanied by a list of the co-ordinate points. A list of the wall and backfill co-ordinates will be output, along with a list of soil properties, in response to the user command W(WRITE).

The output is the same as that used in the data check process (section 5.2.5) and achieved by a call to subroutine DATACH (section 5.3.6).

5.3.12.15 Provide temporary change to alphanumeric mode

When the user wishes to type headings for screen display it is necessary to temporarily remove the cross-hairs and introduce the cursor before switching the terminal over to local mode. By typing E(ERASE) the cursor will disappear and the echo will be switched off. A call to SENDIN is then made and the program will only return to interactive mode and restore the cross-hairs when the user signifies his readiness by typing a carriage return.

5.3.12.16 User assistance for changing section

The list of user commands (Figure 4.19) is output directly on the screen by a series of SENDHS commands.

5.3.12.17 Provide base key

A base key can be provided at three stages during the program. The prompts for input of details of the key shape are contained in subroutine KEYS (section 5.3.9).

5.3.12.18 Provide boundary for display

The instructions for forming a border for the display are contained in subroutine BORDER (section 5.3.2). The instructions are stored in the display file and a call to DEPICT is necessary before the border is output.

5.3.12.19 Redraw checks

When the wall shape has been amended and a re-draw requested it is necessary to check the points of intersection of the ground in front of the wall with the wall face, and, when there is a standing water level, the intersection point of this with the wall back.

These points are originally calculated in the main program however a re-draw is purely a graphical process with no re-analysis and so provision has to be made in the graphics subroutine to check these points.

When the amended section is re-drawn the factors of safety relating to the previously analysed section are left on the screen for reference purposes. The user is reminded that those values no longer relate to the currently displayed section by the symbol R placed after the factors of safety.

5.3.12.20 Check on x-co-ordinates of wall

In trial runs of the program it was found that on occasions errors arose because of the difficulty of obtaining accurate positioning of co-ordinates with the cross-hairs. For example an attempt to make a surface vertical sometimes resulted in the surface having a slight backward slope. This condition led to a program "hang-up" when an attempt was made to calculate the wall weight.

This error condition can satisfactorily be avoided by making a check on all x-co-ordinates of the wall following wall amendment and before re-analysis is attempted. The check is simple. The x-co-ordinates defining the wall cross-section are worked through sequentially and the value of each term checked against the value of the previous one. If any term is found to be smaller than the previous one an error condition is imminent and is avoided by setting the offending term equal to the term before it.

5.3.13 Subroutine STRIPS

Prior to calculating the weight of a trial wedge it is necessary to arrange the wedge shape into a series of vertical strips. While the term 'wedge' is used when considering the failure 'block' this soil mass may have a complicated shape (Figure 5.29).

Before calling STRIPS the top and bottom contours of the wedge must be stored in arrays XTOP( ), YTOP( ) and XBOT( ), YBOT( ) (Figure 5.29). The number of entries in each array is stored as NTOP and NBOT.

Given these two arrays subroutine STRIPS will divide the wedge shape into a series of vertical strips as shown in Figure 5.29. Four stages can be identified in the process. These are shown as a simplified flow diagram in Figure 5.30.

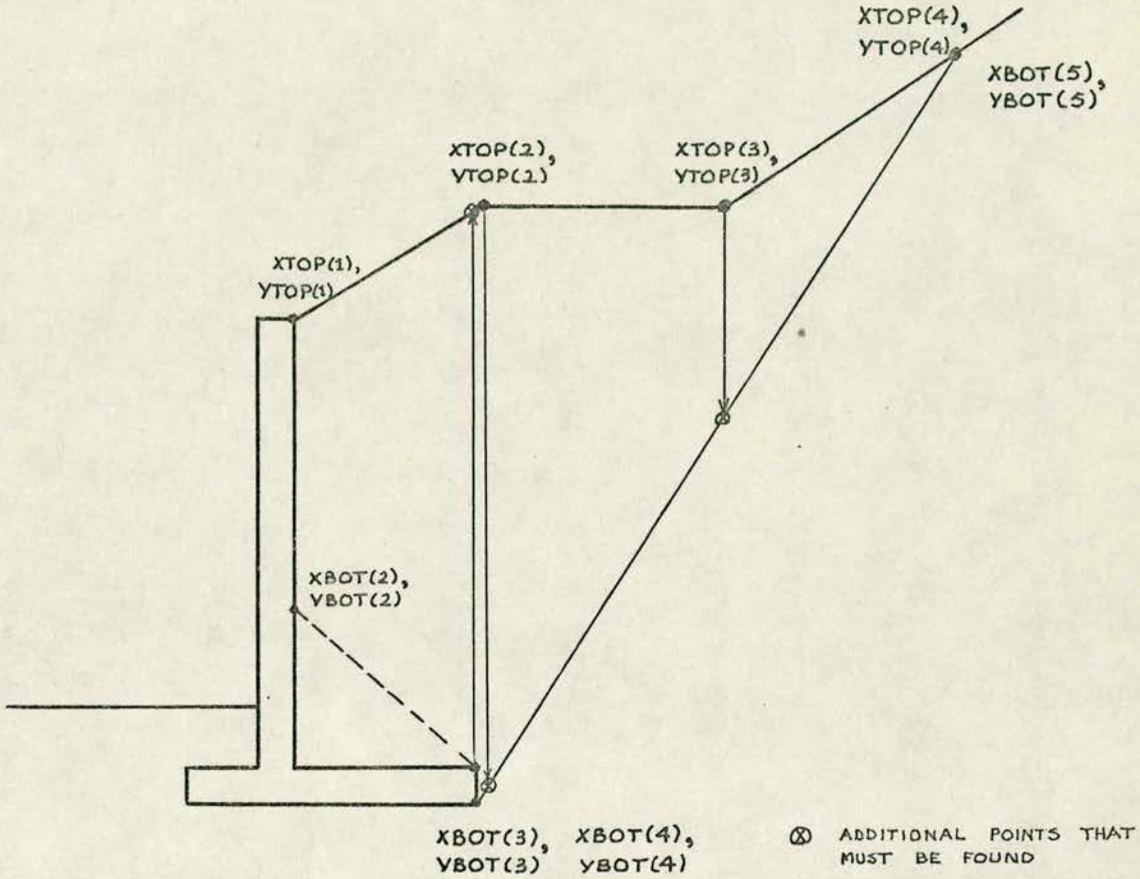


FIG. 5.29. : DEFINITION OF TOP AND BOTTOM SURFACES FOR SUBROUTINE STRIPS

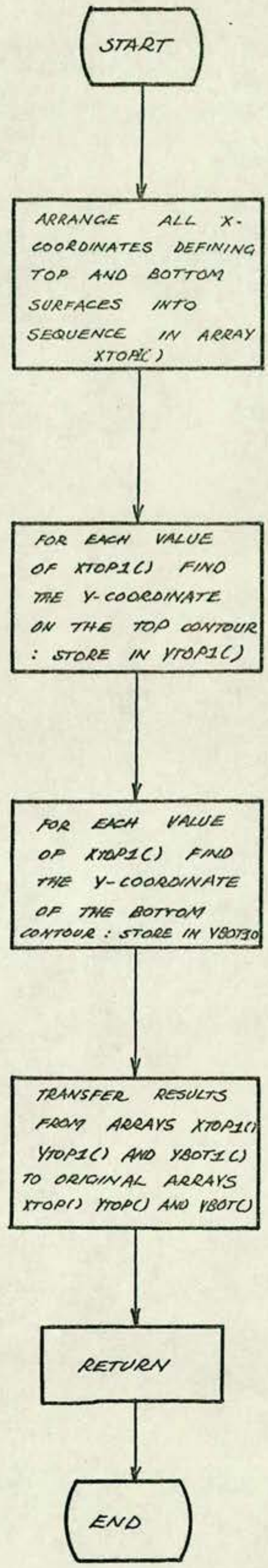


FIG. 5.30. SIMPLIFIED FLOW DIAGRAM FOR SUBROUTINE STRIPS

The subroutine will return with the amended strip data stored in the original arrays XTOP( ), YTOP( ) and YBOT( ).

5.3.14 Subroutine SUM

In subroutine WEIGHT after the calculation of the area and moment of each strip by subroutine COG it is necessary to calculate the weight of the strip and add data this to the term used to keep a summation of the strip weights SUMWT. The total moment of the wedge about the y-axis SUMMTY must also be incremented after each strip has been considered.

Both these operations are carried out by subroutine SUM. The density of the material in the strip must be provided as an argument in the call to the subroutine.

5.3.15 Subroutine TANGNT

Subroutine TANGNT is another subroutine used solely in connection with the friction circle method for calculating passive earth pressure. This routine is used to find the line of action of the resultant force on the curved portion of the slip surface.

This resultant is known to pass through the point (XRES, YRES) and to be tangent to the friction circle centre (XCENTR, YCENTR) and radius RADIUS.

There will of course be two lines which satisfy this condition. However the direction of movement of the soil wedge is known and the correct lines of action can be selected.

The routine returns with the line of action of the resultant stored as ANGF and the co-ordinates of the tangent point as XT, YT.

5.3.16 Subroutine TIGER

When considering cohesive soils vertical tension cracks will develop in the soil behind the wall as shown in Figure 5.31. The position of the tension crack behind the wall has to be found and subroutine TIGER will do this.

The flow diagram in Figure 5.32 summarises the procedure for finding the position of the tension crack. A list of variable names used in the subroutine is given in Figure 5.33.

5.3.17 Subroutine WEIGHT

This subroutine is used to calculate the weight of a soil wedge. The wedge must be defined as a series of strips each strip corresponding to a discontinuity in the wedge shape (Figure 5.29). This is achieved by using three arrays XTOP(I), YTOP(I), YBOT(I) to define the soil wedge.

The subroutine will also deal with a soil wedge which is partially saturated. The water level is stored in WATER.

Given the data described above, along with the dry and submerged soil densities, WEIGHT will establish the centre of gravity of the wedge and its overall weight. This is done by considering each strip in turn and

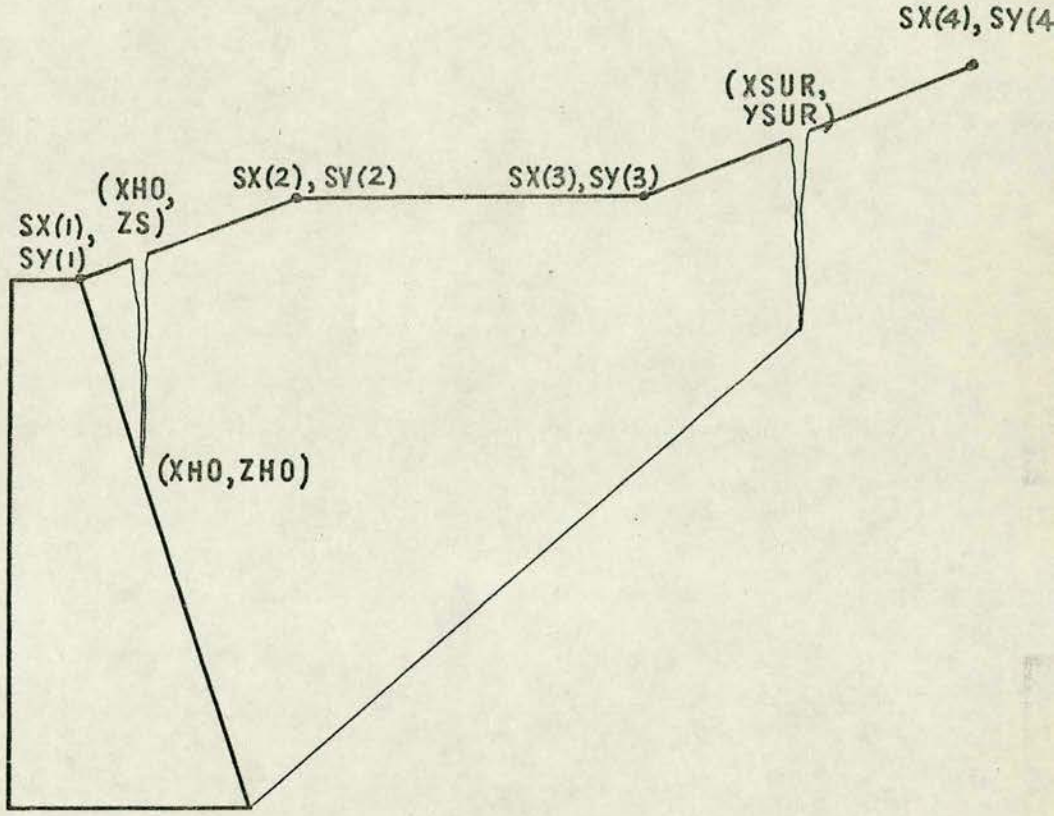


FIG. 5.31. : POSITION OF TENSION CRACK ON WALL BACK

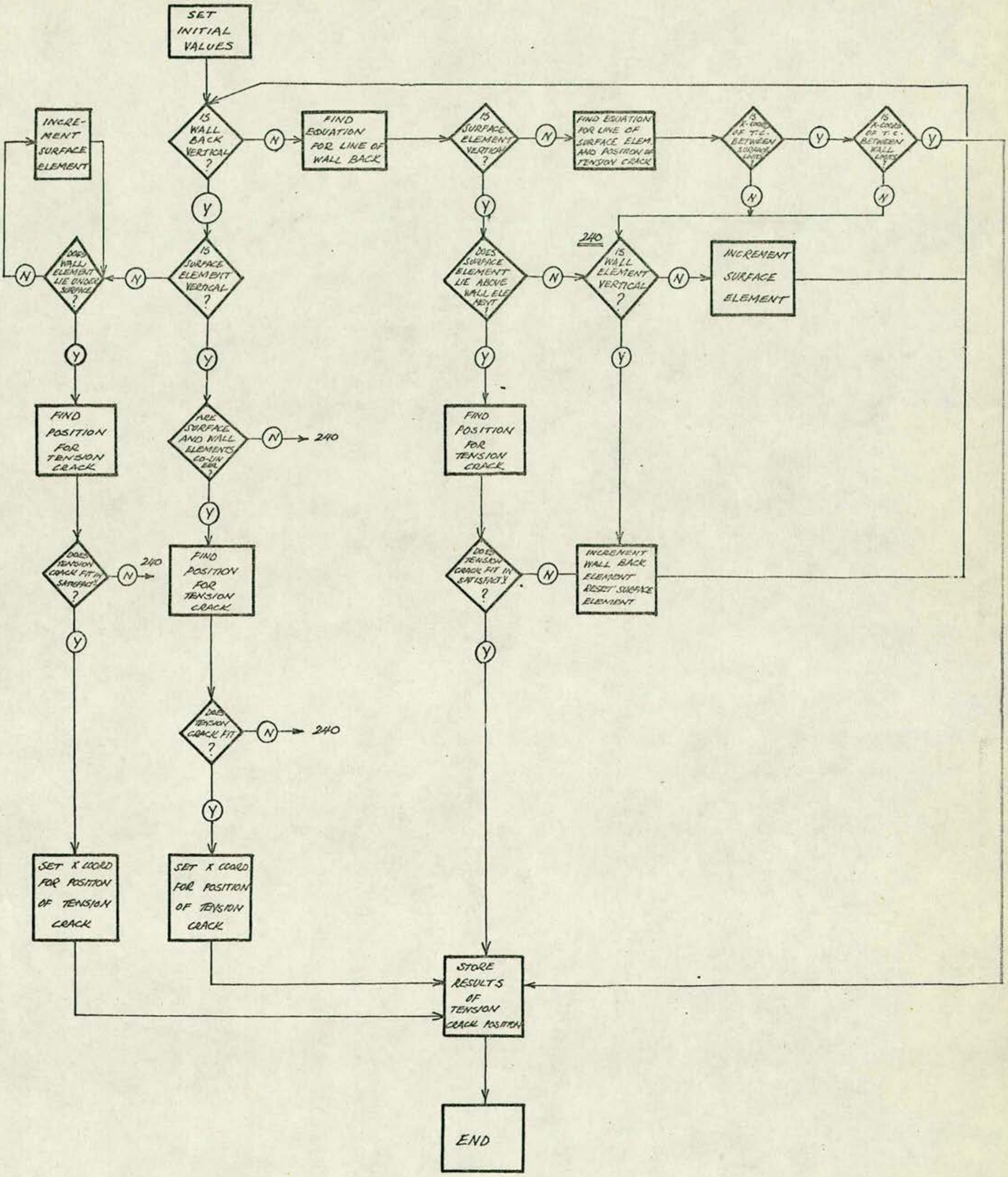


FIG. 5.32. : FLOW DIAGRAM FOR SUBROUTINE TIGER

CBACK : constant term in equation for line of wall back element

CSURF : constant term in equation for line of surface element

I : current wall element being considered is WX(I), WY(I) → WX(I+1), WY(I+1)

INO : record of which wall element is intersected by tension crack

J : current surface element being considered is SX(J), SY(J) → SX(J+1), SY(J+1)

JNO : record of which surface element is intersected by tension crack

JSTART : first suface co-ordinate after intersection of tension crack

SLOPEB : slope of current wall back element

SLOPES : slope of current surface element

TCSURW : weight of any surcharge acting above wedge between wall·back and tension crack

XHØ : x-co-ordinate of position of tension crack

ZHØ : y-co-ordinate of bottom of tension crack

ZS : y-co-ordinate of top of tension crack

Figure 5.33: NOMENCALTURE FOR SUBROUTINE TIGER

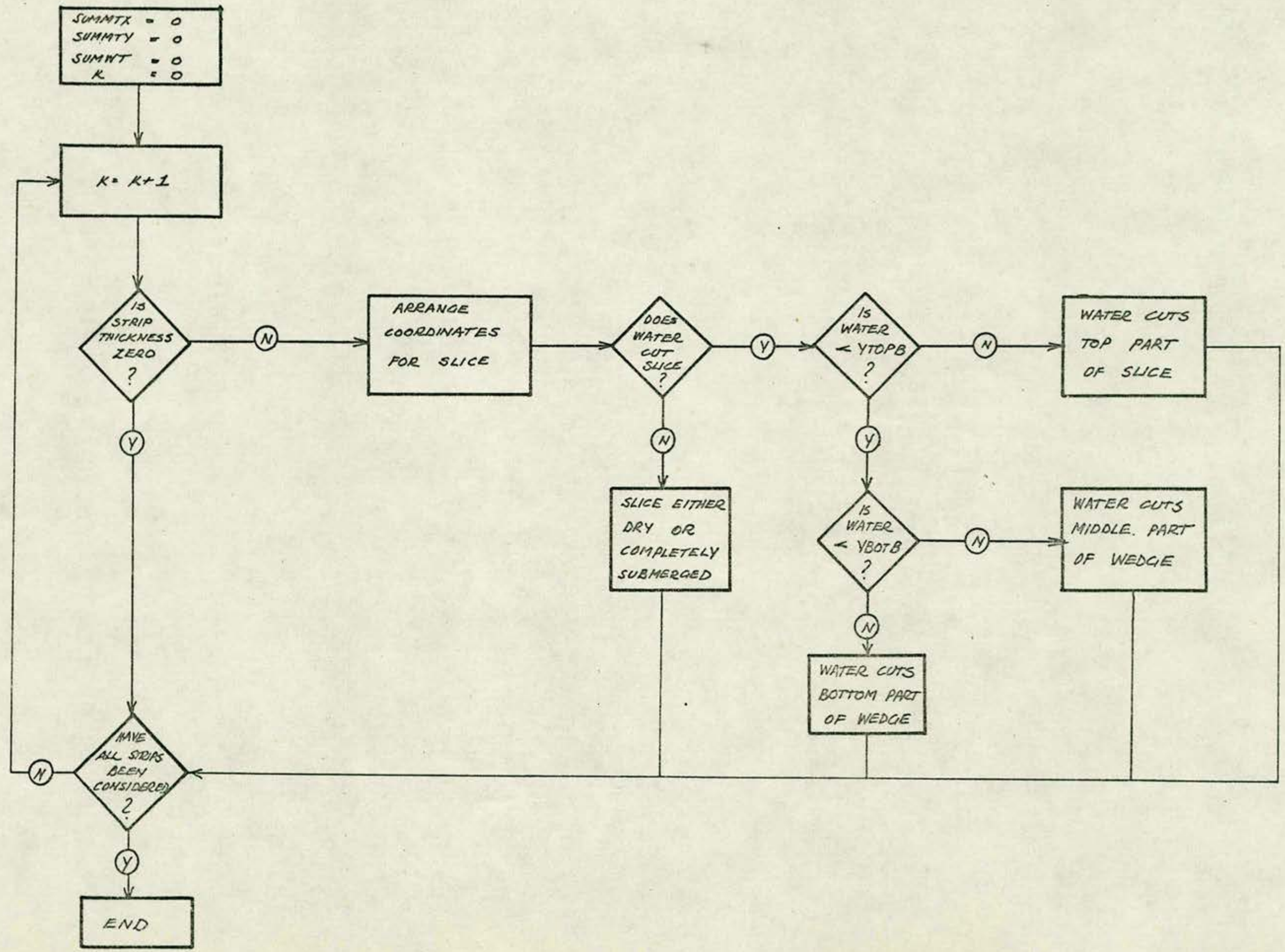


FIG. 5.34.: SIMPLE FLOW DIAGRAM FOR SUBROUTINE WEIGHT

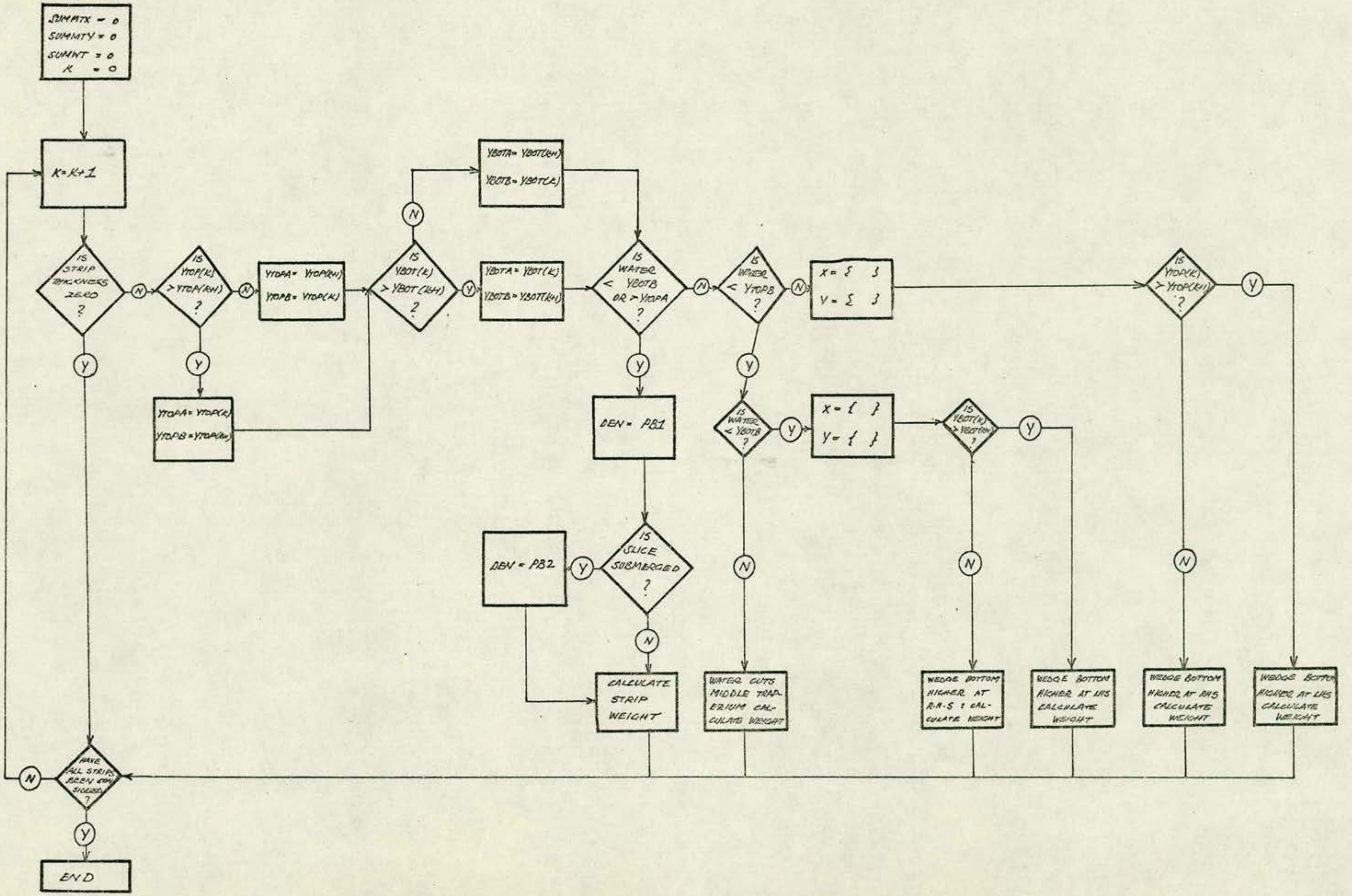


FIG. 5.35. : DETAILED FLOW DIAGRAM FOR SUBROUTINE WEIGHT

CHAPTER 6

PROGRAM TRIALS

6.1 INTRODUCTION

As a way of checking the program a series of twenty seven trial examples were run. Fifteen of these trails are concerned with gravity walls. The remainder consider cantilever walls. All the trial examples are taken from textbooks or papers on retaining wall design. Where possible the factors of safety obtained by the program are compared with the book values. Where the book does not calculate the factors of safety a comparison is made between the values for the active earth force.

When comparing the program and book results agreement to within 5% is considered satisfactory. Generally the results agree to within 3% however because of the sources of error present no exact comparison is justifiable. There are two possible sources of error. Firstly when forming the data files for the examples it was necessary to scale the dimensions for the walls and backfill surfaces from drawings in the books. The accuracy of such a process is of course limited. The second source of error lies with the book analysis methods. These are invariably based on graphical techniques and the critical active force obtained from such methods can only be read to an accuracy of at the best 3%.

Where the program results were found to differ from the book results by more than 5% a more detailed comparison of the analysis was made. This check generally revealed some fundamental difference in the analysis techniques which meant that comparison of the results was not justified. On two occasions the checks revealed that approximations used in the book examples were responsible for the difference in results.

The scope of the trials is summarized in Figures 6.1 and 6.3 while the results themselves are listed in Figures 6.2 and 6.4. Details of the sections analysed and the program results are contained in Appendices II and III.

An example of the use of the automatic design procedure is illustrated and discussed in section 6.4.

6.2 GRAVITY WALL TRIALS

Of the fifteen trial examples for gravity walls only two (trials G3 and G11) permit direct comparison to be made between book and program values of factors of safety. In trial G12 the factor of safety against sliding FSLID can be compared. For the remainder of the examples a comparison can be made between the book and program values for the active earth force PA.

Trails G10, G11 and G12 consider gravity walls with heel projections. These walls are analysed by both the simple and Included Wedge Methods. In trial G12 an included wedge surface is considered in the book example and this is compared with one of the program included wedge surfaces.

Trials G1 to G6 consider plane backed gravity walls under a variety of different backfill surface shapes and loading conditions. For all these trials the program values for the active force agree with the book values to within 3%. Only in trial G2 can the point of application of the active force be compared.

Figure 6.1: SUMMARY OF GRAVITY WALL TRIALS

TRIAL NO.	WALLBACK	BACKFILL SURFACE	SOIL TYPE	SURFACE LOADING	WATER	SOURCE
G 1	Plane	Plane	Cohesionless	None	None	Hu p. 77
G 2	Plane	Plane	Cohesionless	Continuous U.D.L.	None	Hu p. 91
G 3	Plane	Plane	Cohesionless	Continuous U.D.L.	None	Ha p.308
G 4	Plane	Plane	Cohesionless	None	None	Hu p. 78
G 5	Plane	Irregular	Cohesionless	None	None	Hu p. 82
G 6	Plane	Irregular	Cohesionless	Irregular	None	Hu p. 87
G 7	Plane	Plane	Cohesionless	None	Yes	Hu p.183
G 8	Plane	Plane	Cohesionless	None	Yes	K p.116
G 9	Bi-planar	Plane	Cohesionless	None	None	Hu p.130
G 10	Tri-planar	Plane	Cohesionless	None	None	B p.339
G 11	Tri-planar	Plane	Cohesionless	None	None	Hu p.442
G 12	Tri-planar	Plane	Cohesionless	None	None	Hu p. 96
G 13	Plane	Plane	Cohesive	None	None	Hu p.239
G 14	Plane	Irregular	Cohesive	None	None	Hu p.243
G 15	Plane	Irregular	Cohesive	Irregular	None	Hu p.247

B: Bowles[4]
Ha: Hairsine[8]
Hu: Huntington[9]
K: Karol[12]

Figure 6.2: SUMMARY OF GRAVITY WALL RESULTS

TRIAL	TERM	BOOK	PROGRAM
G 1	PA	17200	17457
	APA	44°	43°
	XPA	-	56.96
	YPA	-	6.76
G 2	PA	41000	41127
	APA	43°	43°
	XPA	48.20	48.41
	YPA	10.00	10.18
G 3	PA	87.10	97.00
	FSTIP	3.58	3.92
	FSLID	2.18	2.27
	FSBCY	1.04	1.05
G 4	PA	20400	20414
	APA	50°	50°
	XPA	-	34.28
	YPA	-	10.14
G 5	PA	20500	21272
	APA	50°	48°
	XPA	-	46.70
	YPA	-	9.17
G 6	PA	49000	49942
	APA	51°	50°
	XPA	-	46.75
	YPA	-	10.85

TRIAL	TERM	BOOK	PROGRAM
G 7	PA	25000	25581
	APA	50°	50°
	XPA	47.98	47.96
	YPA	10.80	10.87
	PW	13250	13281
	APW	70°	70°
	XPW	49.49	49.49
	YPW	6.67	6.67
G 8	PA	1025	1013
	APA	60°	60°
	XPA	41.00	41.00
	YPA	3.33	3.38
	PW	3120	3120
	APW	90°	90°
	XPW	41.00	41.00
	YPW	3.33	3.33
G 9	PATOP	17500	17583
	APATOP	45°	45°
	XPATOP	47.52	47.33
	YPATOP	11.00	11.39
	PABOT	4400	4130
	APABOT	70°	70°
	XPABOT	50.77	50.77
	YPABOT	2.00	1.95

TRIAL	TERM	BOOK	PROGRAM SIMPLE	IW
G 10	FSTIP	2.19	2.28	2.14
	FSLID	1.57	1.59	1.53
	FSBCY	1.09	1.09	1.04
G 11	FSTIP	-	3.10	3.03
	FSLID	2.10	2.42	2.33
	FSBCY	-	1.06	1.03
G 12	WEDANG	62°		62°
	PATOP	3500		3530
	PABOT	10400		10233
	PABASE	3000		3231
	FSTIP	-	6.28	6.64
	FSLID	-	3.04	3.22
	FSBCY	-	1.86	1.41
G 13	PA	57080	55035	
	APA	58°	60°	
	XPA	54.45	54.45	
	YPA	-	9.76	
G 14	PA	35000	35911	
	APA	68°	68°	
	XPA	48.34	48.33	
	YPA	22.03	23.02	
G 15	PA	64500	66344	
	APA	64°	64°	
	XPA	-	49.37	
	YPA	-	9.08	

Figure 6.3: SUMMARY OF CANTILEVER WALL TRIALS

TRIAL NO.	BACKFILL SURFACE	SOIL TYPE	SURFACE LOADING	WATER	SOURCE
C 1	Plane	Cohesionless	None	None	B p.344
C 2	Plane	Cohesionless	None	None	W p.264
C3 3	Plane	Cohesionless	None	None	Hu p. 81
C 4	Plane	Cohesionless	Irregular	None	T p.339
C 5	Plane	Cohesionless	Continuous U.D.L.	None	Hu p. 91
C 6	Plane	Cohesionless	Continuous U.D.L.	None	Ha p,304
C 7	Bi-planar	Cohesionless	Irregular	None	Hu p. 89
C 8	Irregular	Cohesionless	None	None	Hu p. 85
C 9	Plane	Cohesive	None	None	Hu p.241
C 10	Plane	Cohesive	Continuous U.D.L.	None	Ha p.315
C 11	Irregular	Cohesive	None	None	Hu p.244
C 12	Irregular	Cohesive	Irregular	None	Hu p.249

B: Bowles[4] Ha: Hairsine[8] Hu: Huntington[9] T: Teng[26] W: Wollaston[31]

Figure 6.4: SUMMARY OF CANTILEVER WALL RESULTS

TRIAL	TERM	BOOK	PROGRAM		COMMENTS
			SIMPLE	I/W	
C 1	FSTIP	2.28	2.21	2.28	No key
	FSLID	1.12	1.11	1.14	
	FSBCY	-	1.07	1.06	
	FSTIP		2.21		2'00" key: no active pressure on key
	FSLID	1.34	1.33	-	
	FSBCY		1.07		
	FSTIP	-	2.2.		3'00" key: no active pressure on key
	FSLID	1.46	1.46	-	
	FSBCY	-	1.07		
	FSTIP	-	2.27	2.39	2'00" key: active pressure on key
	FSLID	-	1.18	1.23	
	FSBCY	-	1.10	1.10	
	FSTIP	-	2.33	2.47	3'00" key: active pressure on key
	FSLID	-	1.22	1.28	
	FSBCY	-	1.12	1.12	
C 2	FSTIP	2.70	2.93	3.12	
	FSLID	1.79	1.83	2.00	
	FSBCY	-	1.89	1.60	

TRIAL	TERM	BOOK	PROGRAM		COMMENTS
			SIMPLE	I/W	
C 3	PA	15400	15255		
	APA	75°	75°		
	XPA	49.00	49.00		
	FSTIP		2.71	2.79	
	FSLID		1.57	1.57	
	FSBCY		1.70	1.12	
C 4	FSTIP	2.11	2.06	2.63	
	FSLID	1.52	1.47	1.75	
	FSBCY		1.49	1.69	
C 5	PA	24000	24798		
	APA	80°	80°		
	XPA	52.00	52.00		
	YPA	10.60	10.97		
	FSTIP		2.63	2.77	
	FSLID		1.38	1.54	
	FSBCY		0.95	0.78	
C 6	FSTIP	3.65 (2.99)	2.89	2.97	
	FSLID	2.19 (1.79)	1.75	1.84	
	FSBCY	0.96 (0.84)	0.82	0.83	
	PA	87.1 (106.5)	109		
	APA	90°	90°		
	XPA	43.30	43.30		
	YPA	1.93	1.95		

TRIAL	TERM	BOOK		PROGRAM		COMMENTS
				SIMPLE	I/W	
C 7	PA	24500		24755		
	APA	79°		79°		
	XPA	10.60		10.57		
	YPA	49.00		49.00		
	FSTIP			1.55	2.25	
	FSLID			0.73	0.72	
	FSBCY			1.03	1.27	
C 8	PA	10400		10989		
	APA	78°		77°		
	XPA	50.00		50.00		
	YPA	-		8.00		
	FSTIP			3.67	4.34	
	FSLID			1.17	1.24	
	FSBCY			1.65	0.96	
C 9	PA	34000		36366		
	APA	85°		85°		
	XPA	54.00		54.00		
	YPA	-		9.69		
	FSTIP			4.27	3.02	
	FSLID			1.04	0.79	
	FSBCY			1.94	0.93	

TRIAL	TERM	BOOK	PROGRAM		COMMENTS
			SIMPLE	I/W	
C 10	PA	162.10	220.48		
	FSTIP		1.47	1.00	
	FSLID		1.76	1.35	
	FSBCY		1.35	1.11	
C 11	PA	30500	27835		
	APA	80°	80°		
	XPA	50.00	50.00		
	YPA	-	8.61		
	FSTIP		2.76	2.33	
	FSLID		0.95	0.78	
	FSBCY		1.36	1.23	
C 12	PA	45000	45155		
	APA	82°	83°		
	XPA	54.00	54.00		
	YPA	10.40	10.33		
	FSTIP		1.78	2.34	
	FSLID		0.44	0.46	
	FSBCY		0.95	1.16	

Trials G7 and G8 consider plane backed walls when there is a standing water level behind the wall. Both examples give values for active and water forces to within 3% of the book values.

A gravity wall with a bi-planar back is considered in trial G9. In this example a comparison can be made both with the magnitude and point of application of the two active forces. The active force on the top part of the wall agrees to within 1% with the book value while the bottom force is within 5% of the book value.

Trials G10, G11 and G12 consider gravity walls with heel projections. These are considered as tri-planar wall backs and as such are analysed by both the Simple and Included Wedge methods. In trial G10 Bowles neglects the heel projection replacing it by an equivalent plane wall back. Despite this approximation the results obtained are found to be very similar to those obtained by both the Simple and Included Wedge methods. This example is however one of the few occasions when the Included Wedge method yields factors of safety against sliding and overturning less than the Simple analysis method when considering a cohesionless soil. The reason for this condition stems from the particular wall shape under analysis. With the small heel projection very steep included wedge surfaces are considered. For such surfaces the horizontal components of the active force are greater than for the shallower surfaces considered when the heel projection is large. The resulting effect is a decrease in the wall stability against overturning and sliding, and an increase in wall stability against bearing failure. When the analysis is carried out by the Simple Method however the active force on the vertical plane remains unchanged provided the heel position remains fixed. Any attempt to increase the heel projection by making the top part of the wall back more steep is equivalent to replacing a volume of wall by an equal amount of soil. With soil being less dense than the wall material this has the effect of decreasing the stabilizing forces. Consequently as the size of a heel projection increases the factors of safety against sliding and overturning as calculated by the Simple Method tend to decrease while those calculated by the Included Wedge Method tend to increase.

In trial G11 Huntington neglected the heel projection and used Coulombs equation to calculate the active force on an equivalent plane wall back. The book results cannot therefore be compared with either of the program results. Only the factor of safety against sliding is calculated in the book example and this is found to be some 13% smaller than the values calculated by the program. Again the Included Wedge analysis gives factors of safety smaller than those obtained by the Simple method, the reason again being the very small heel projection present.

In trial G12 the heel projection is somewhat greater than in trials G10 and G11, with the wall assuming a cantilever wall shape. The values for the factors of safety against sliding and overturning found by the Included Wedge analysis now exceed those found by the Simple analysis method. For this particular example Huntington considers failure along an included wedge surface and direct comparison can be made between his results and those obtained from one of the programs trial included wedges. The values for the top and bottom active forces, PATOP and PABOT, agree to within 2% of the book values while PABASE, the active force on the heel projection agrees to within 7%.

Trials G13, G14 and G15 all consider plane backed gravity walls supporting backfills of cohesive material. In all these examples the program results for the active forces agree with the book values to within 3%. For all three examples the effect of water in the tension cracks was not considered in the book calculations and the program was temporarily amended to give a compatible analysis procedure.

6.3 CANTILEVER WALL TRIALS

Twelve trial examples are run for the analysis of cantilever retaining walls. A diagram of the wall shape, list of basic data and summary of results for each cantilever trial is given in Appendix II. The scope of the trials is summarized in Figure 6.3 and the summary of the results given in tabular form in Figure 6.4.

The first cantilever trial (C1) considers a cantilever wall both with and without a base key. On introduction of the key the analysis method used by Bowles did not make allowance for additional active pressure acting on the key back. The program was temporarily amended so that it too would neglect active pressure on the heel and thus permit direct comparison to be made between the program and book results. Bowles used a "simple-type" analysis method and only the program Simple Method is used when assessing the factor of safety against sliding in the presence of the keys. As is seen in Figure 6.4 the results obtained by the program agree almost exactly with the book values. For completion the two sections with heel keys are run under the program proper with the additional active pressure on the heel being considered in the analysis process. The resulting factors of safety against sliding are found to fall some 15% below the values obtained when the active pressure on the heel was neglected.

The factors of safety obtained in trial C2 show the expected differences for simple and included wedge analysis with FSTIP and FSLID being greater for Included Wedge analysis while FSBCY is greater for Simple analysis. The program results for FSTIP cannot however be compared with the book results because of the unusual method used by Wollaston to calculate the factor of safety. The equation used by Wollaston for the calculation of FSTIP is

FSTIP = Weight of wall + weight of soil above heel / PA

The book value for the factor of safety against sliding is calculated in the same manner as in the program and differs from the program value (Simple value) by 4%.

In trial C3 the active force calculated by the Simple method agrees with Huntington's value to within 1%. Huntington did not consider the wall stability, however the Simple and Included Wedge methods show results of the expected form.

Teng considered the factors of safety against sliding and overturning failure for the wall section used in trial C4. The values obtained for these factors of safety by the Simple method agree with Teng's values to within 3%. The values obtained by the included wedge method are again 20 - 25% greater than those obtained using the simple analysis procedure.

In trial C5 the active earth force on the vertical plane through the heel calculated by the Simple Analysis Method agrees with the value obtained by Huntington to within 4%. The results for the factors of safety obtained by the Simple and Included Wedge Methods show the expected difference with the factors of safety against sliding and overturning being greater for the Included Wedge Method.

Trial C6 is the first metric example of cantilever wall analysis. The book value for the active earth pressure on a vertical plane through the heel of the wall is about 20% less than the program value. This is because Hairsine uses a Ka value of 0.27 for calculating the active force. The program does not use Rankines Method but would have a Ka equivalent of 0.33. If Hairsine's Ka value is amended to 0.33 the book value of PA increases from 87.1 to 106.5. Using this new value the book values for the factors of safety are recalculated and shown in brackets in Figure 6.4. These amended factors of safety can be compared with the results obtained by the program. The program results agree closely with the amended book values.

Trial C7 is the first cantilever example to consider a non-planar backfill surface. The simple values for the magnitude and point of application of the active force agree with Huntington's results to within 1%. The included wedge analysis gives factors of safety which are all greater than those obtained by the simple analysis method.

In trial C8 the program value for the active force on a vertical plane through the heel is some 6% greater than the value obtained by Huntington. This difference is somewhat larger than in previous trials and is the result of an approximation used by Huntington which leads to the trial wedge weight being underestimated.

Trial C9 is the first cantilever trail to consider a cohesive backfill. It is generally found that when considering cantilever analysis with a cohesive backfill the Included Wedge Method gives factors of safety somewhat lower than those obtained when the Simple Analysis Method is used. This trial is one such case. When considering cohesionless soils it was generally found that the Included Wedge Analysis Method gave FSTIP and FSLID values greater than those from the Simple Method. With cohesive soils the reverse is true. Several factors contribute to this condition however perhaps the most important is the fact that cohesive soils have very low ϕ and δ values. The line of action of the active forces in the Included Wedge Method is decided by the value of these terms. In the Simple Method the line of action of the active earth force is still ascertained using the empirical rule suggested in the AREA Manual.

Trial C10 is the only cohesive example where consideration has been given to water in the tension crack in the book analysis. However Hairsine unfortunately uses a different equation for calculating the depth of tension crack from the one used in the program. Hairsines calculations have been adjusted after making the tension crack depth the same as the value obtained in the program. The resulting amended values for the factors of safety are shown in Figure 6.4 in brackets after the original book values. These agree closely with the program values obtained from the Simple Analysis Method. The factors of safety as calculated by the Included Wedge Method are a good deal less than the values obtained by the Simple Method.

Trial C11 gives a value for the active force on a vertical plane through the heel of the wall some 9% smaller than the book value. A detailed analysis was made of the book calculation and this showed that Huntington's approximation for calculating wedge weights was far from exact and overestimated the wedge weight. For the critical failure wedge the book value for the wedge weight was 6% greater than the true wedge weight. The factors of safety calculated by the Included Wedge Method are again lower than those obtained by the Simple Method.

The factor of safety results in trial C12 show the Included Wedge results to be greater than the Simple results. This does not agree with the previous cohesive results where Included Wedge results were all less than the Simple results.

A detailed inspection of the two analysis methods reveals the reason for the apparent discrepancy. In the Simple analysis because the ground rises comparatively steeply behind the wall back the vertical plane through the heel is relatively large. When the active pressure is considered on this surface the resultant active force has a large vertical lever arm. This has the effect of producing rather large overturning moment and accounts for the low value of FSTIP given by the Simple Method. This example highlights the sensitivity of the simple method to the shape of the ground surface behind the wall as this has a bearing both on the size of the surface upon which active forces are considered and the angle at which the active force is assumed to act. The results obtained by the program using the simple analysis agree very closely to the results obtained by Huntington.

6.4 AUTOMATIC CANTILEVER DESIGN EXAMPLE

The ground surface data and soil properties used in trial Cl are used to illustrate the workings of the automatic cantilever design procedure. The data file for this trial is shown in Figure 6.5.

Initially a fairly wide analysis was carried out considering toe depths of 2.00, 4.00, 6.00 and 8.00 feet and toe:base ratios of .20, .40 and .60. The results from this analysis are shown in Figures 6.6, 6.7 and 6.8. From these results the minimum wall weight is found at a toe depth of 2.00, although this does not correspond to the minimum base width.

```
8
 36.630  17.000
 36.630  19.000
 39.630  19.000
 40 170  45.000
 41.000  45.000
 41.000  19.000
 50.000  19.000
 50.000  17.000
2
 41.000  45.000
241.000  80.260
115.000 115.000
  0.590   0.400
000.000 000.000
  0.400  0.400
5000.0009000.000
000.000
  6.000  19.000
  0.000   0.000
 00.000
  1.50    2.000
  2.000   1.500    1.000
 26.00
 000.000
150.000
```

FIG 6.5 : DATA FILE FOR AUTOMATIC DESIGN EXAMPLE

TOE DEPTH	RATIO	BASE	WALL WEIGHT
2.00	0.20	20.00	12450.00
2.00	0.40	20.00	12450.00
2.00	0.60	28.00	14250.00
4.00	0.20	20.00	13050.00
4.00	0.40	18.00	12600.00
4.00	0.60	24.00	13950.00
6.00	0.20	22.00	14100.00
6.00	0.40	16.00	12750.00
6.00	0.60	20.00	13650.00
8.00	0.20	22.00	14700.00
8.00	0.40	18.00	13800.00
8.00	0.60	16.00	13350.00

DATE : 17-OCT-73	AUTOMATIC ANALYSIS : TABLE OF RESULTS	TRIAL NO. :

FIG 6.6 : TABULATED RESULTS FOR FIRST AUTOMATIC DESIGN

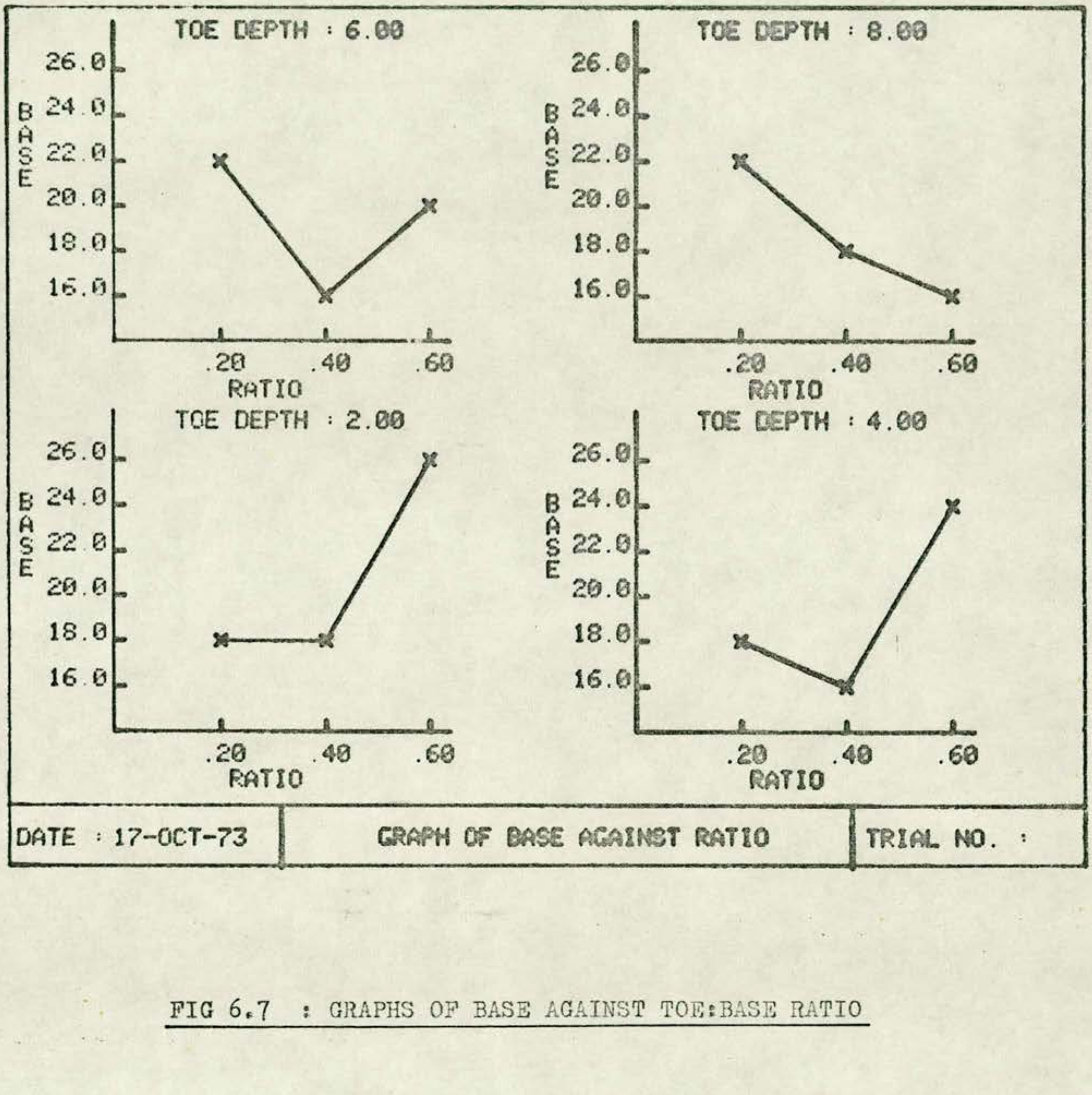


FIG 6.7 : GRAPHS OF BASE AGAINST TOE:BASE RATIO

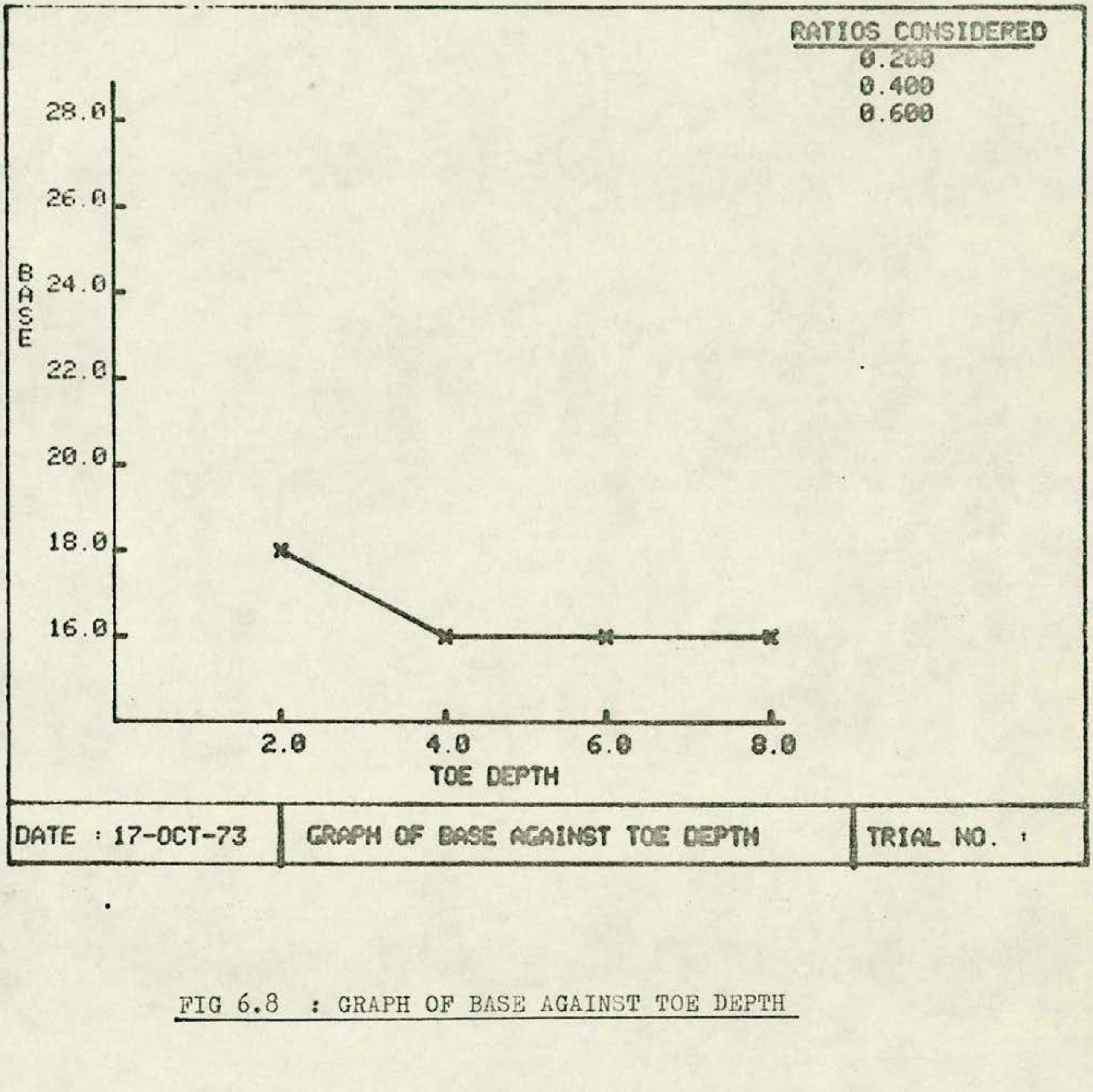


FIG 6.8 : GRAPH OF BASE AGAINST TOE DEPTH

In the light of these results a second and more detailed analysis was selected covering toe depths of 2,00, 2.50, 3.00,3.50 and 4.00 feet and toe:base ratios of 0.20, 0.25, 0.30, 0.35 and 0.40. The results from this second analysis are shown in Figures 6.9, 6.10 and 6.11. These results show that for all the toe depths considered a minimum base width occurs at a toe:base ratio of 0.30. From inspection of the table of results the minimum wall size is found to occur at a toe depth of 2.00 and toe:base ratio of 0.30.

One final analysis was run this time over just one toe depth of 2.00 ft but considering toe:base ratios of 0.27, 0.28, 0.29, 0.30, 0.31, 0.32 and 0.33. The results from this analysis are given in Figures 6.12 and 6.13. From this analysis a minimum wall section is found at a toe depth of 2.00 ft and a toe:base ratio of 0.28.

This example shows the sort of design progression possible with the automatic design process. Here the search has been for the minimum wall section to provide stability. It must be remembered that no structural design of the wall units has been considered and that for a cost optimization process this would be required. The inclusion of such a facility in the program is discussed in chapter 7, section 7.2.

TOE DEPTH	RATIO	BASE	WALL WEIGHT
2.00	0.20	19.00	12225.00
2.00	0.25	17.50	11887.50
2.00	0.30	17.00	11775.00
2.00	0.35	18.50	12112.50
2.00	0.40	19.50	12337.50
2.50	0.20	19.00	12375.00
2.50	0.25	17.50	12037.50
2.50	0.30	17.00	11925.00
2.50	0.35	18.00	12150.00
2.50	0.40	19.50	12487.50
3.00	0.20	19.50	12637.50
3.00	0.25	17.50	12187.50
3.00	0.30	16.50	11962.50
3.00	0.35	18.00	12300.00
3.00	0.40	19.00	12525.00
3.50	0.20	19.50	12787.50
3.50	0.25	18.00	12450.00
3.50	0.30	16.50	12112.50
3.50	0.35	17.50	12337.50
3.50	0.40	18.50	12562.50
4.00	0.20	19.50	12937.50
4.00	0.25	18.00	12600.00
4.00	0.30	17.00	12375.00
4.00	0.35	17.00	12375.00
4.00	0.40	18.00	12600.00

DATE : 15-OCT-73	AUTOMATIC ANALYSIS : TABLE OF RESULTS	TRIAL NO. :

FIG 6.9 : TABULATED RESULTS FOR SECOND AUTOMATIC DESIGN

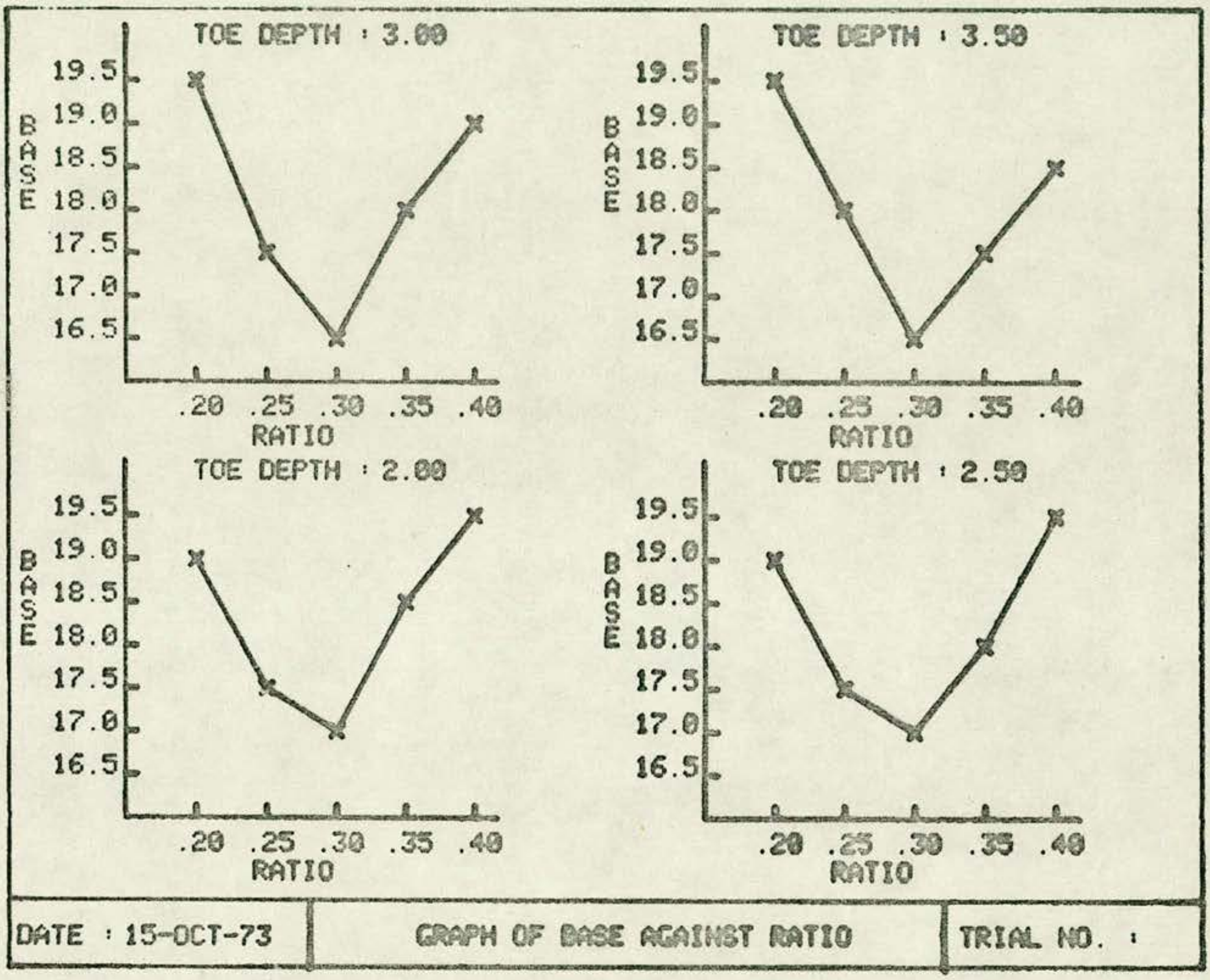


FIG 6.10 : GRAPHS OF BASE AGAINST TOE:BASE RATIO FOR SECOND DESIGN

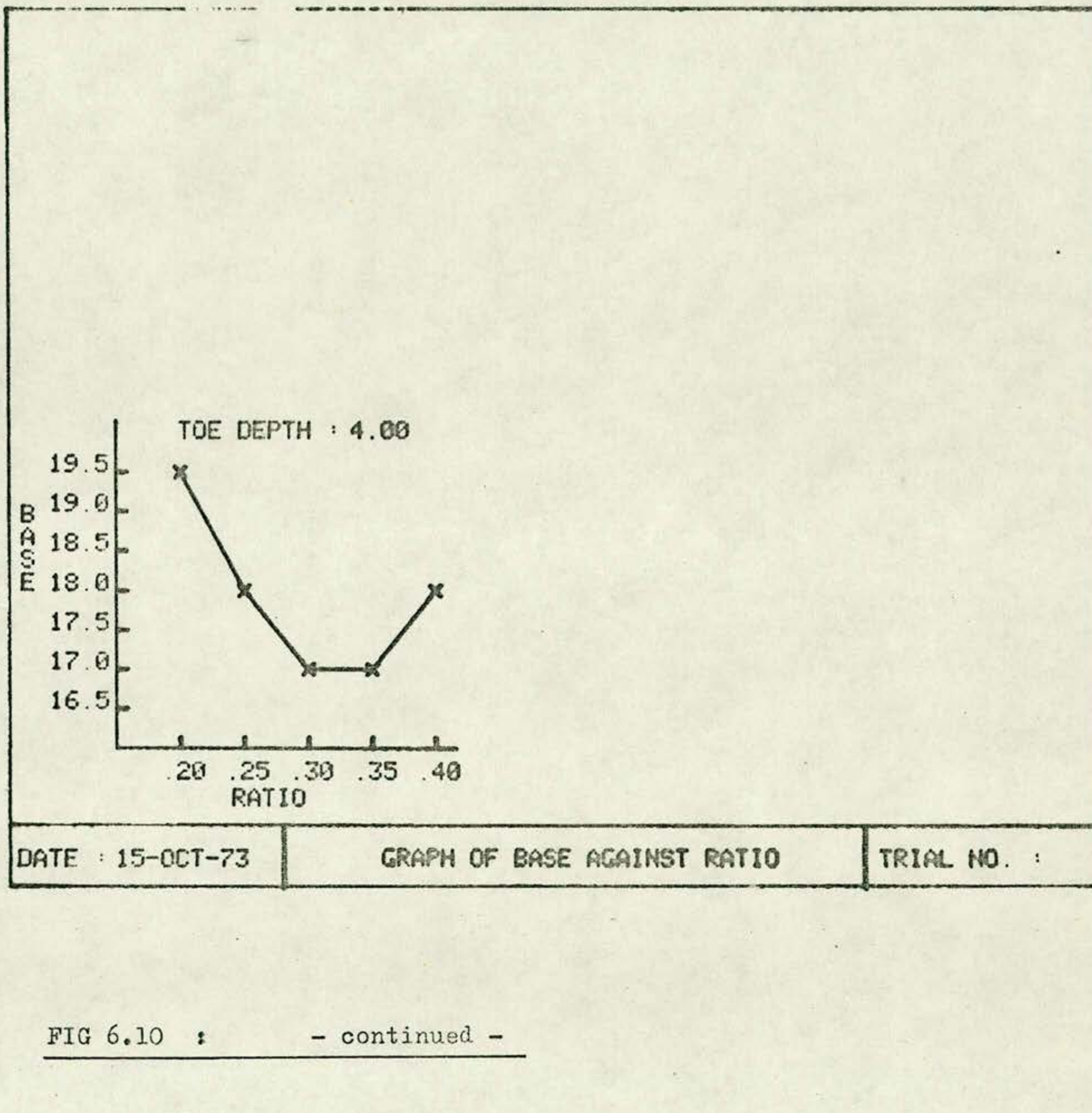


FIG 6.10 : - continued -

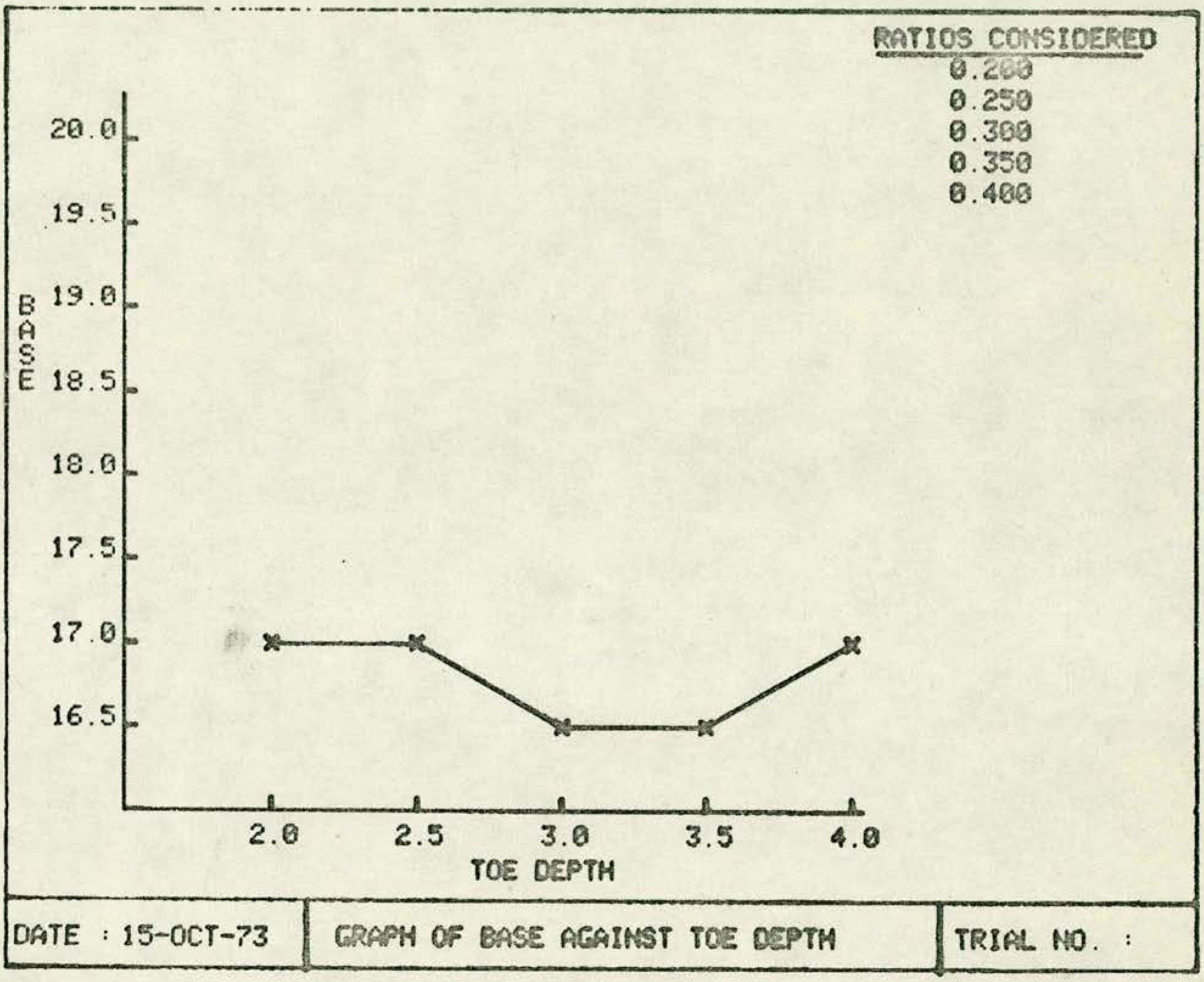


FIG 6.11 : GRAPH OF BASE AGAINST TOE DEPTH FOR SECOND DESIGN ATTEMPT

TOE DEPTH	RATIO	BASE	WALL HEIGHT
2.00	0.27	16.70	11707.50
2.00	0.28	16.50	11662.50
2.00	0.29	16.70	11707.50
2.00	0.30	16.90	11752.50
2.00	0.31	17.20	11820.00
2.00	0.32	17.40	11865.00
2.00	0.33	17.60	11910.00

DATE : 16-OCT-73	AUTOMATIC ANALYSIS : TABLE OF RESULTS	TRIAL NO. :

FIG 6.12 : TABULATED RESULTS FOR FINAL DESIGN ATTEMPT

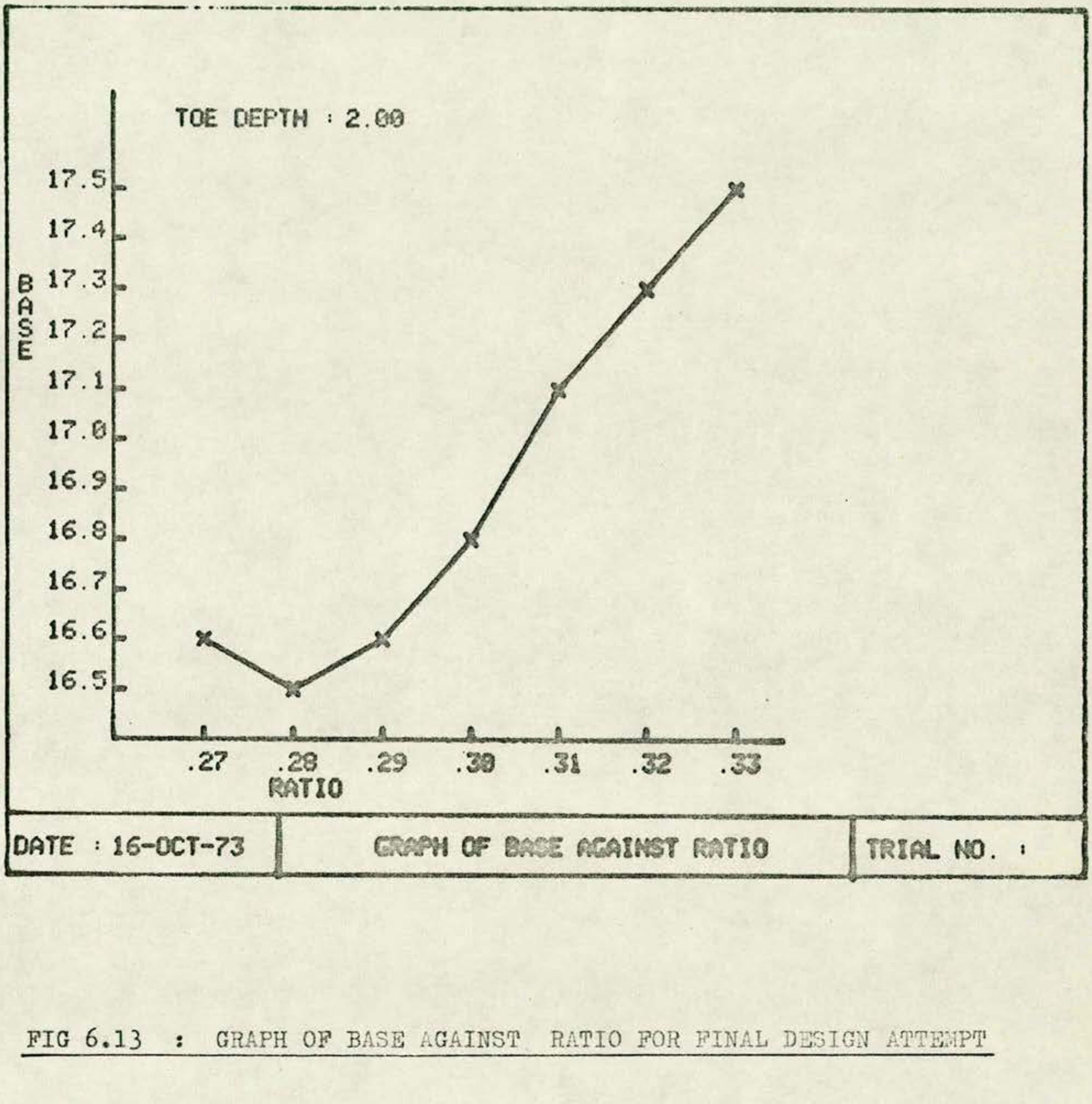


FIG 6.13 : GRAPH OF BASE AGAINST RATIO FOR FINAL DESIGN ATTEMPT

6.5 SUMMARY

The results from the various trials have been discussed in sections 6.2 and 6.3. These results show:-

(i) where compatible analysis methods are used the program values for active earth force agree with the book values.

(ii) the program Included Wedge results agree with Huntington's results for an included wedge surface (trial G12).

(iii) there is no predictable relationship between Simple and Included Wedge analysis results. This is because of the many factors which affect the Simple analysis method. Of these the most important are

(a) the height of soil above the heel of the wall,

(b) the line of action of the active force as determined by the shape of the backfill surface,

(c) the nature of the backfill material, cohesionless or cohesive.

(iv) it is not possible to find a direct relationship between the Simple and Included Wedge results. However the trial results obtained do suggest certain trends. When considering cohesionless soils the Simple analysis tends to give factors of safety against overturning and sliding smaller than those obtained from the Included Wedge analysis. These have been found to be up to 30% less than the Included Wedge results.

In contrast to these results the factor of safety against bearing failure tends to be greater when calculated by the Simple Method. Values have been found to be up to 30% higher than those obtained by the Included Wedge Method.

When considering cohesive soils the results are somewhat different with the Simple Analysis Method tending to give values for the factors of safety of up to 40% greater than the Included Wedge Analysis method. Although as the results of trial C12 show this is not always the case.

The example of the automatic cantilever design procedure illustrates how useful the graphics facilities can be when it comes to presentation of results. The graphs of base against toe depth and base against toe:base ratio permit the rather lengthy results from the automatic analysis to be presented in a form that can be quickly assessed by the designer.

CHAPTER 7

CONCLUSIONS AND SUGGESTIONS FOR PROGRAM DEVELOPMENT

7.1 CONCLUSIONS

The object of this work has been to provide an interactive graphics program for the primary design of retaining walls. As such the work can be considered as being in two parts. First it was necessary to select and program a suitable method for the analysis of a retaining wall. Having established the analysis process it was then necessary to consider the interactive and graphical facilities available and to decide how these facilities could be best incorporated in the program. The selection of an analysis method was discussed in chapters 2 and 3, and a detailed description of the graphics and interactive facilities and of how to use them was given in chapters 4 and 5.

The trial examples in chapter 6 were undertaken as a means of checking the workings of the program and of comparing the results obtained from the Simple and Included Wedge methods. The results obtained in the trials were discussed in chapter 6. From these results it is clear that the Simple method does not give results that show any close agreement with those obtained from the Included Wedge method. The Included Wedge method is based upon theoretical considerations of the failure of the soil wedge behind a cantilever wall. The Simple method is very much an approximate method which is shown by the trial examples to be rather unpredictable. In the light of these results the

Simple analysis method cannot be recommended. It could be that a detailed investigation of the results of a large number of trials would make it possible to establish rules which would allow the Simple analysis results to be adjusted so as to become compatible with those obtained from the Included Wedge method. However in the absence of such information the Included Wedge method should be used in preference to the Simple method.

On the general question of the application of computer graphics to the problem of retaining wall design the program illustrates several advantages offered by the graphics facilities. However with no experience of an equivalent non-graphics program it is impossible to make a direct comparison between such a program and this graphics program. However having read about a number of existing non-graphics programs developed elsewhere it is possible to speculate on the relative advantages offered by the graphics.

The graphics facilities are used in essentially two processes: user interaction and the output of results. For the analysis of one proposed wall shape, identified in the program as manual analysis, the results are output in the form of three factors of safety. Such results can obviously be output as easily on a conventional teletype terminal as on a visual display unit. However when the automatic design process is used this is not the case. The ability to output the results graphically is a tremendous advantage. To obtain an idea of how the base width varies with changes in toe depth and toe:base ratio a graph is by far the quickest and simplest method. A graph permits the overall trend in the results to be assessed at a glance. This is of course not as easy when the results are output in tabular form. As a record of the results obtained a table may be ideal, however for assessment of those results a graph is invaluable. When it comes to the adjustment of a proposed section it is found that for the manual analysis process this is most conveniently done graphically, while for the automatic design process it is more convenient to specify the next area for analysis numerically. With the manual analysis process the absence of graphical output of the section shape would make it necessary for the designer to work from a sketch of the wall cross-section. To attempt to work from a list of co-ordinates would indeed prove a laborious process.

It is therefore in two main processes that the graphics facilities show considerable advantages. However throughout the program the increased speed of writing possible with the visual display unit makes it possible to use processes and provide facilities which would be quite out of the question when working with a conventional teletype terminal. None of the menu selection processes would be feasible. While this is not of great consequence when selection is from a short list of alternatives, when a long list is involved, as in the data change process, a completely different procedure would have to be utilised. Any process that involved the output of a large amount of data would more or less have to be abandoned because of the prohibitive amount of time required for such processes on conventional teletypes. An example of such a process in this program is the output of a list of wall and ground surface co-ordinates. If operating via a conventional teletype this process would have to be replaced by some method whereby the data to be output could be stored in a disk file and output later after exiting from the program. Very fast output of alpha-numeric information could be obtained with the lineprinter. However when operating on a timesharing system from a remote terminal there are two problems. Firstly, unless there happened to be a lineprinter at the remote terminal, which will be indeed unlikely, the output from the lineprinter will have to be conveyed from the printer to the remote terminal. Secondly, when operating under a timesharing system direct access to the lineprinter will seldom be possible.

The visual display unit offers therefore for this particular application considerable advantages. The importance of speed of communication cannot be overemphasised. The very nature of interactive programming relies upon speedy communication between man and machine. Where such communication cannot be guaranteed the benefits offered by interactive programming will be severely curtailed.

When dealing with wall stability consideration was given to sliding, overturning and bearing failure. As such the program is very much concerned with the stability of the wall itself. It should be pointed out however that any proposed design should be checked for failure of the complete slope. Such failure is often referred to as deep-seated failure. No provision for such an analysis has been made in the program as such an analysis involves consideration of the whole question of the stability of slopes.

The second section of this chapter considers some possible developments which may prove worthy of future implementation. Of these the provision of some form of secondary design analysis for the structural design of wall elements is by far the most important. With such a facility the program would be capable of undertaking the complete design of earth retaining walls.

7.2 SUGGESTIONS FOR PROGRAM DEVELOPMENT

The object of this work has been to produce a program capable of carrying out the primary design stage for arriving at the overall wall dimensions. The program has been kept as general as possible and can cater for most design cases. However for completeness of design the program should be extended to include provision for the secondary design stage. Some amendment will be required to the format of the results from the primary stage to permit these to be utilized for consideration of the shear forces and bending moments on the various wall elements. However, once the necessary amendments are made to the results retrieval, the design of the elements of a cantilever wall, or the checking of stresses within a gravity wall, becomes a task on it's own and can be developed as an additional subroutine to the program.

Once provision has been made for the secondary design stage the program could well be developed as a commercial proposition. However, before such a development was considered it would probably be constructive to make an assessment of the procedure used in design offices for the design of retaining walls. A survey could be carried out among local consultants to discover how much time is usually spent on a retaining wall design and how efficient a design is arrived at in this time. By costing the design time and the final design it will be possible to obtain a costing for the complete process. This costing could then be compared with designs carried out by computer. Typical computer bureau charges should be used when assessing the cost of the computer design. The results of such an analysis would indicate right away if the program would prove useful commercially and give an indication of what sort of benefits are likely from it's use.

If the program is considered viable for commercial use it would be advantageous to involve some outside consultant as early as possible in the development stage. There is an underlying tendency, when working on a program in the comparatively sheltered atmosphere of a university, to become too deeply involved with theoretical aspects of the program. The advantages of involving a practical engineer in a program have already been observed in this Department in the development of a slope stability program.

No optimization technique has been included in the program for the use of such techniques would require that the wall design could be costed. This would only be possible if the various elements were designed structurally. However if a secondary design stage was later incorporated in the program the inclusion of an optimization technique may lead to more effeicint designs than those obtained from an interactive program. Schimming and Fischer (21) have already considered the use of optimization techniques in cantilever retaining wall design[21]. Their investigation was very much an attempt to assess various optimization methods rather than an attempt to develop a sophisticated retaining wall design program. However working from a fairly comprehensive program it could be that the inclusion of an optimization technique would speed up the design process and increase design efficiency. The existing program has been developed very much as an interactive program and, while it would be feasible to include an optimization technique in such a program, it is more likely that these techniques would be used in a program to be run under batch processing. In developing an optimization program for batch processing the existing analysis techniques could be used and the only work required would be the programming of the optimization technique and the restructuring of the program to remove the interactive facilities and permit the program to be run under a batch system.

Both the developments suggested above involve fairly large amendments or additions to the existing program. There are of course many minor developments which are not considered essential and which have not been included in the current program. These include:-

(i) provision for dealing with seepage forces.

(ii) provision for standing water level in front of wall.

(iii) provision for the display of possible restraints on the wall shape i.e. rock outcrops, existing services.

(iv) provision for dealing with layered backfill materials.

Should any of these be considered necessary at a later date it would be hoped that the detailed program description given in chapter 5 would permit the amendments to be made without too much problem.

APPENDIX 1 : GRAVITY WALL TRIALS

WALL COORDINATES

X	Y
48.00	25.00
49.00	45.00
51.00	45.00
60.00	25.00

GROUND COORDINATES

X	Y	SURCHARGE
51.00	45.00	0.00
250.00	98.00	

BACKFILL PROPERTIES

ANGLE OF INTERNAL FRICTION	:	0.52
ANGLE OF WALL FRICTION	:	0.40
DRY DENSITY	:	120.00
SATURATED DENSITY	:	0.00
COHESIVE STRENGTH	:	0.00
ADHESIVE STRENGTH	:	0.00

FRONT CONDITIONS

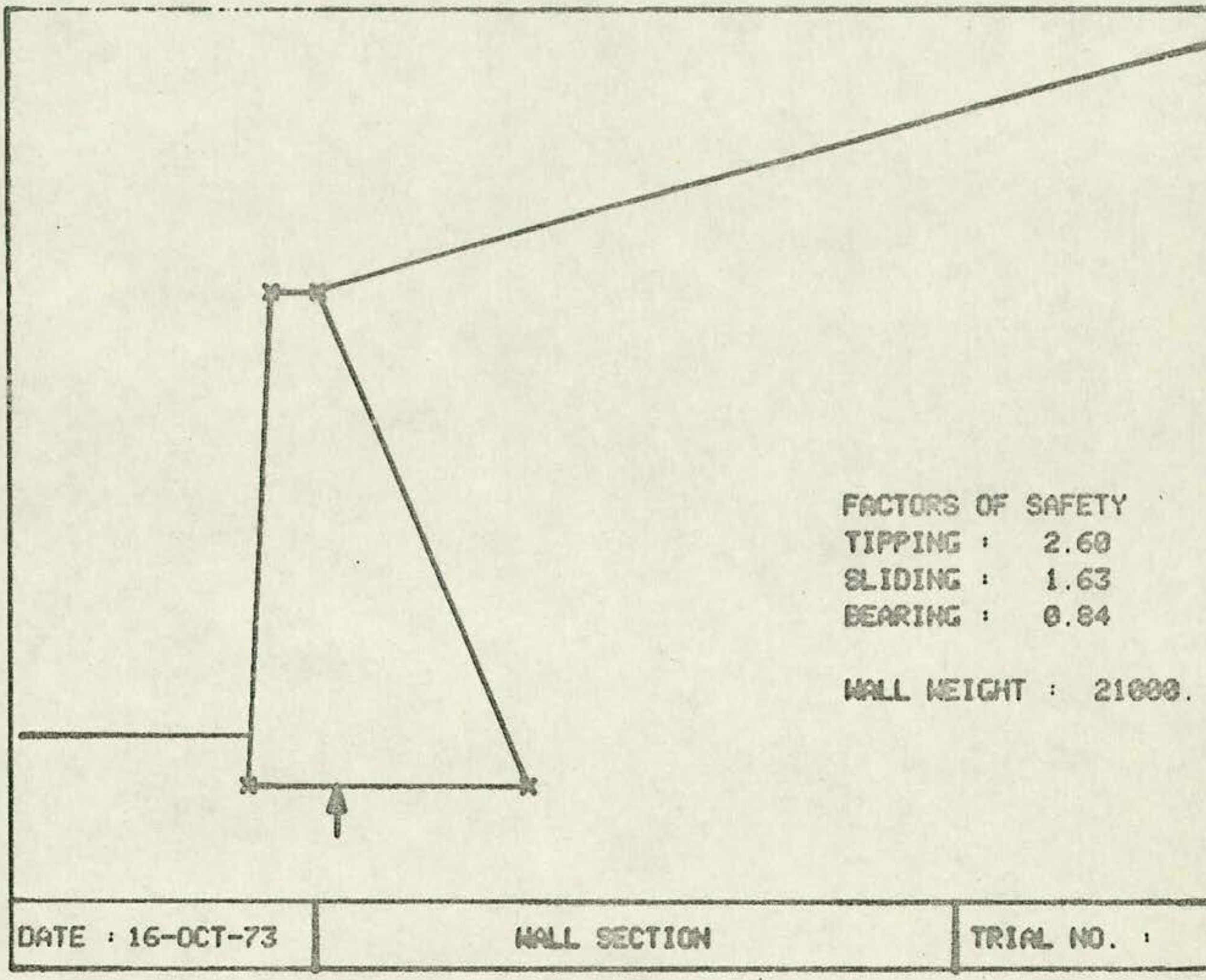
X-COORD	:	6.00
Y-COORD	:	27.00
SLOPE	:	0.00
SURCHARGE	:	0.00

FOUNDATION PROPERTIES

ANGLE OF INTERNAL FRICTION	:	0.52
ANGLE OF WALL FRICTION	:	0.52
BASE ADHESION	:	0.00
BEARING CAPACITY	:	5000.00
BEARING MAXIMUM		0.00

DATE : 16-OCT-73	BASIC DATA	TRIAL NO. :

TRIAL G1 : BASIC DATA



TRIAL G1 : ANALYSIS RESULTS

WALL COORDINATES

X	Y
35.50	20.00
39.00	45.00
41.00	45.00
53.50	20.00

GROUND COORDINATES

X	Y	SURCHARGE
41.00	45.00	1100.00
241.00	80.20	

BACKFILL PROPERTIES

ANGLE OF INTERNAL FRICTION	:	0.52
ANGLE OF WALL FRICTION	:	0.35
DRY DENSITY	:	110.00
SATURATED DENSITY	:	0.00
COHESIVE STRENGTH	:	0.00
ADHESIVE STRENGTH	:	0.00

FRONT CONDITIONS

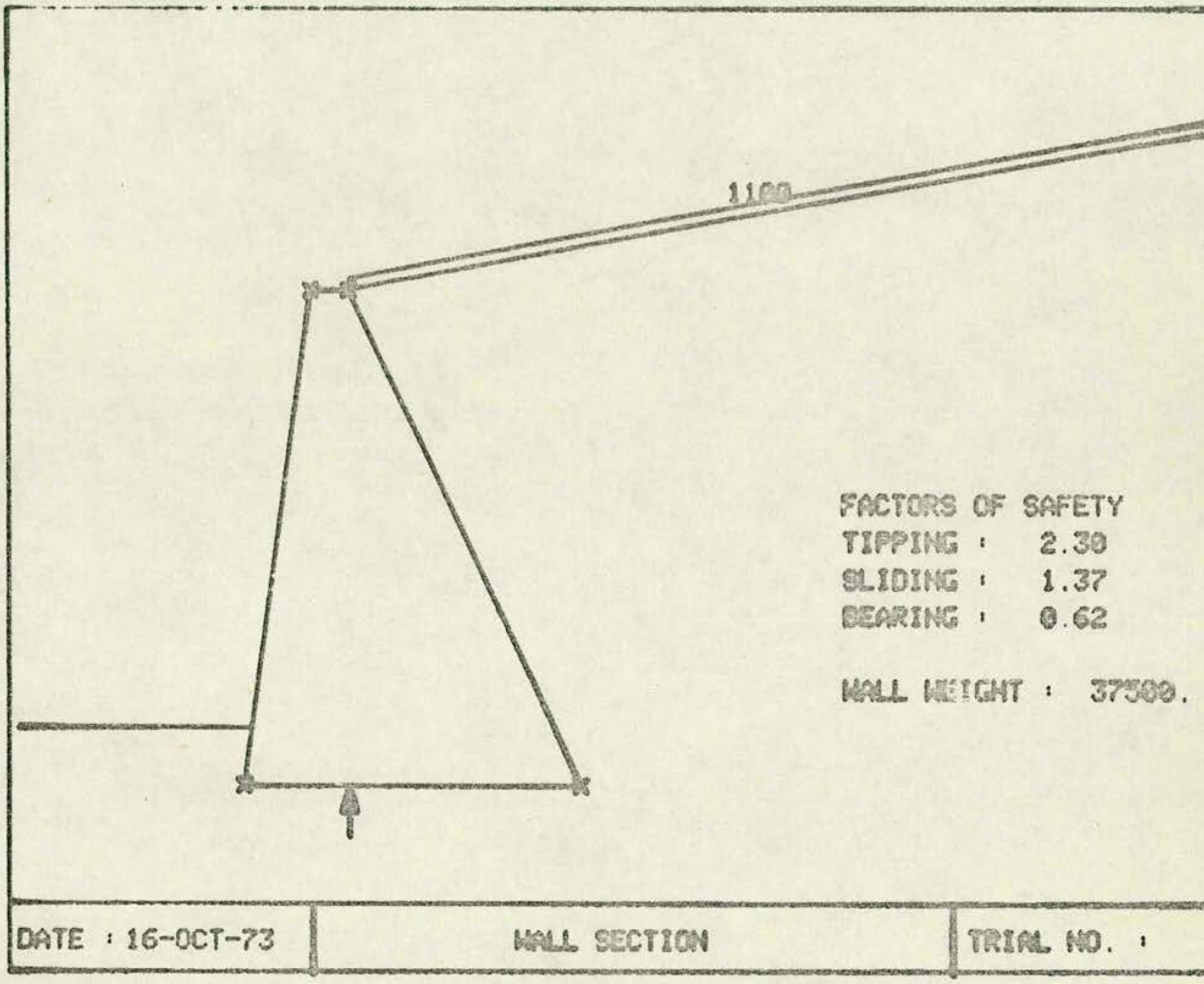
X-COORD	:	6.00
Y-COORD	:	23.00
SLOPE	:	0.00
SURCHARGE	:	0.00

FOUNDATION PROPERTIES

ANGLE OF INTERNAL FRICTION	:	0.52
ANGLE OF WALL FRICTION	:	0.52
BASE ADHESION	:	0.00
BEARING CAPACITY	:	5000.00
BEARING MAXIMUM		0.00

DATE : 16-OCT-73	BASIC DATA	TRIAL NO. :

TRIAL G2 : BASIC DATA



TRIAL G2 : ANALYSIS RESULTS

WALL COORDINATES

X	Y
37.90	39.50
37.90	40.25
38.55	40.50
38.55	45.00
41.00	45.00
41.00	39.50

GROUND COORDINATES

X	Y	SURCHARGE
41.00	45.00	6.00
241.00	45.00	

BACKFILL PROPERTIES

ANGLE OF INTERNAL FRICTION	:	0.52
ANGLE OF WALL FRICTION	:	0.34
DRY DENSITY	:	19.20
SATURATED DENSITY	:	21.58
COHESIVE STRENGTH	:	0.00
ADHESIVE STRENGTH	:	0.00

FOUNDATION PROPERTIES

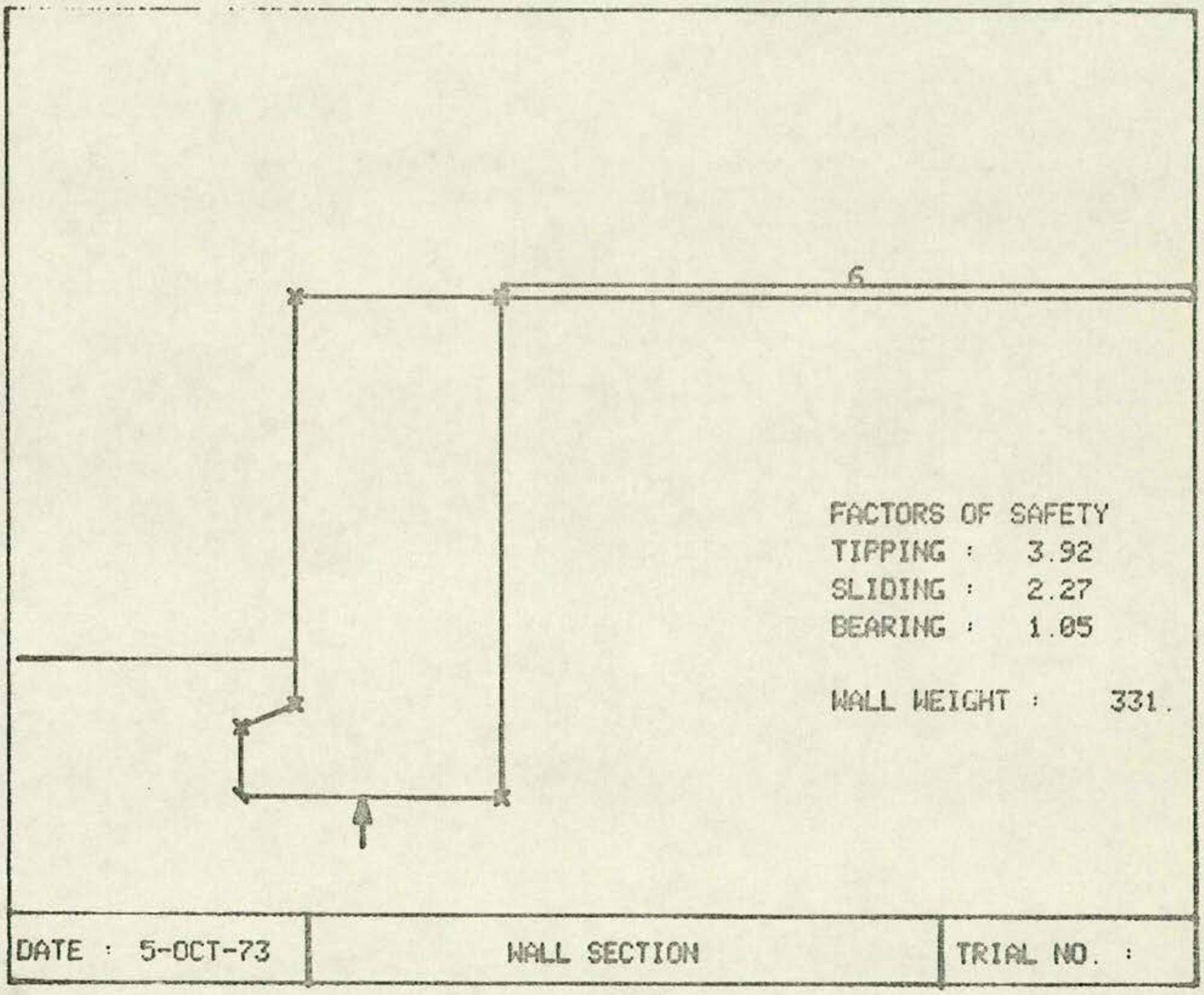
ANGLE OF INTERNAL FRICTION	:	0.52
ANGLE OF WALL FRICTION	:	0.52
BASE ADHESION	:	0.00
BEARING CAPACITY	:	150.00
BEARING MAXIMUM		0.00

FRONT CONDITIONS

X-COORD	:	6.00
Y-COORD	:	41.00
SLOPE	:	0.00
SURCHARGE	:	0.00

DATE : 5-OCT-73	BASIC DATA	TRIAL NO. :

TRIAL G3 : BASIC DATA



TRIAL G3 : ANALYSIS RESULTS

WALL COORDINATES

X	Y
20.00	20.00
20.00	22.00
23.00	24.00
25.00	50.00
27.00	50.00
38.00	20.00

GROUND COORDINATES

X	Y	SURCHARGE
27.00	50.00	0.00
127.00	31.00	

BACKFILL PROPERTIES

ANGLE OF INTERNAL FRICTION	:	0.52
ANGLE OF WALL FRICTION	:	0.35
DRY DENSITY	:	110.00
SATURATED DENSITY	:	0.00
COHESIVE STRENGTH	:	0.00
ADHESIVE STRENGTH	:	0.00

FRONT CONDITIONS

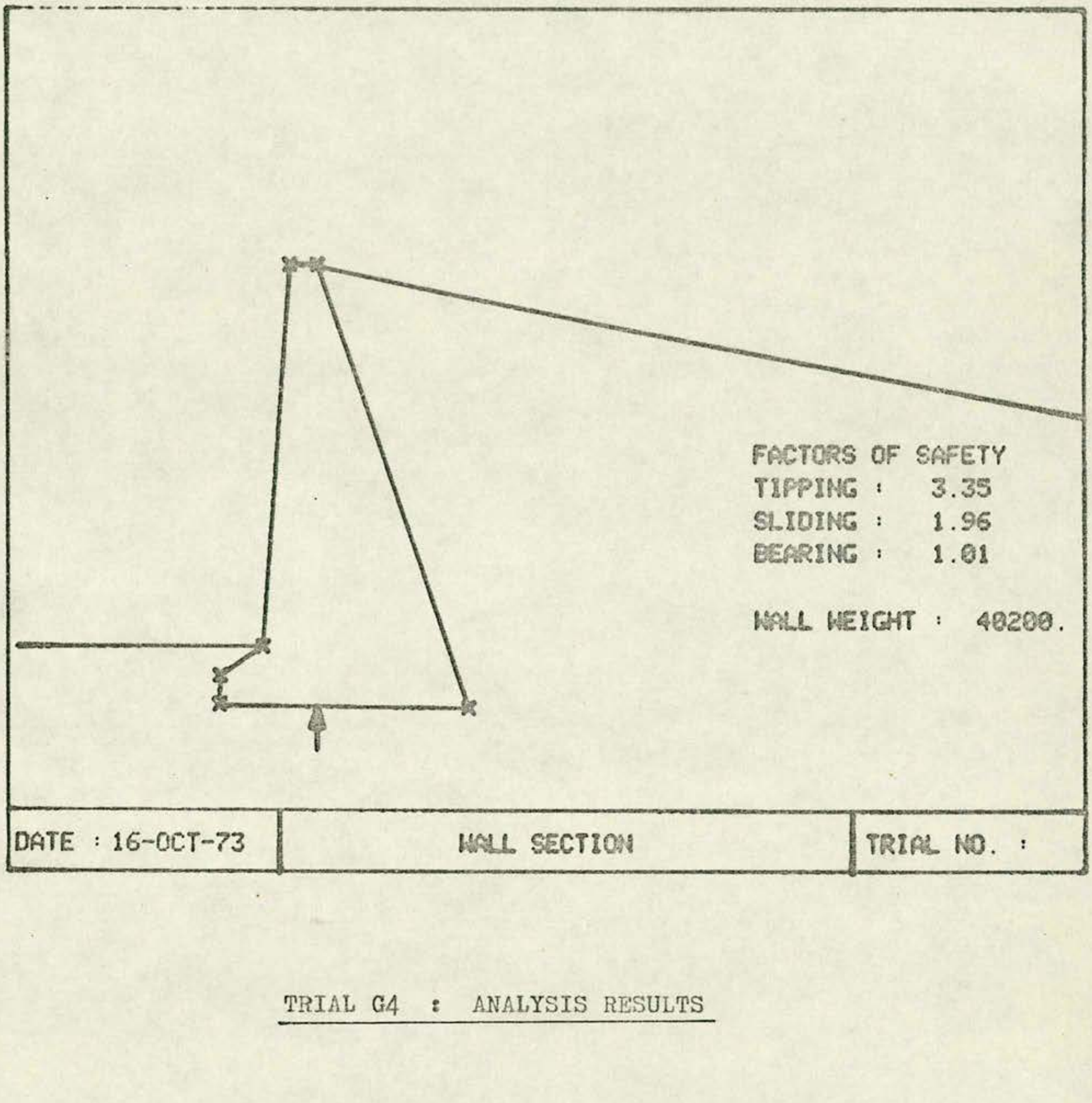
X-COORD	:	6.00
Y-COORD	:	24.00
SLOPE	:	0.00
SURCHARGE	:	0.00

FOUNDATION PROPERTIES

ANGLE OF INTERNAL FRICTION	:	0.52
ANGLE OF WALL FRICTION	:	0.52
BASE ADHESION	:	0.00
BEARING CAPACITY	:	5000.00
BEARING MAXIMUM		0.00

DATE : 16-OCT-73	BASIC DATA	TRIAL NO. :

TRIAL G4 : BASIC DATA



TRIAL G4 : ANALYSIS RESULTS

WALL COORDINATES	
X	Y
35.00	20.00
39.00	45.00
41.00	45.00
50.00	20.00

GROUND COORDINATES		
X	Y	SURCHARGE
41.00	45.00	0.00
48.00	49.00	0.00
63.00	49.00	0.00
68.00	46.00	0.00
170.00	105.00	

BACKFILL PROPERTIES

ANGLE OF INTERNAL FRICTION	:	0.52
ANGLE OF WALL FRICTION	:	0.40
DRY DENSITY	:	110.00
SATURATED DENSITY	:	0.00
COHESIVE STRENGTH	:	0.00
ADHESIVE STRENGTH	:	0.00

FOUNDATION PROPERTIES

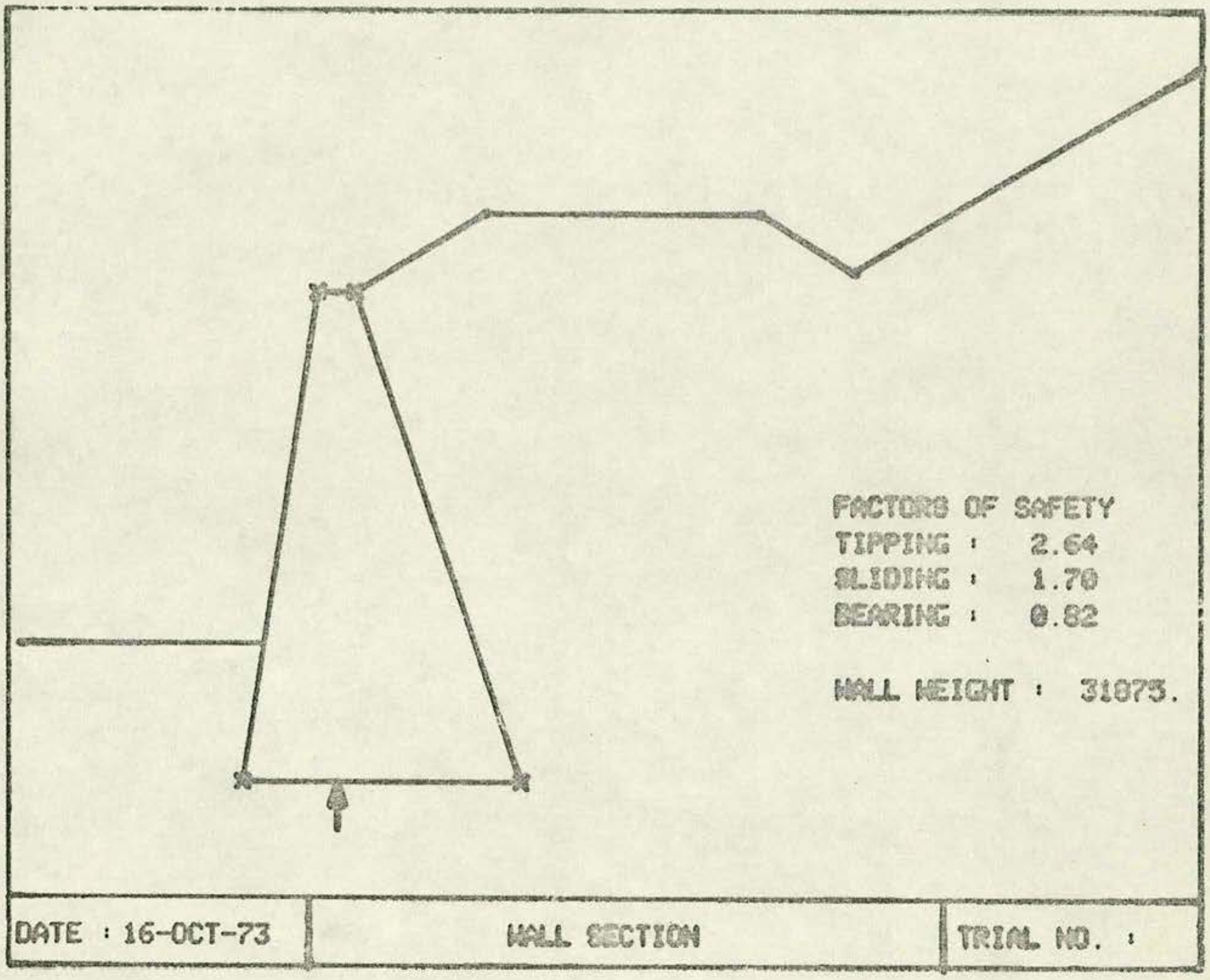
ANGLE OF INTERNAL FRICTION	:	0.52
ANGLE OF WALL FRICTION	:	0.52
BASE ADHESION	:	0.00
BEARING CAPACITY	:	5000.00
BEARING MAXIMUM		0.00

FRONT CONDITIONS

X-COORD	:	6.00
Y-COORD	:	27.00
SLOPE	:	0.00
SURCHARGE	:	0.00

DATE : 16-OCT-73	BASIC DATA	TRIAL NO. :

TRIAL G5 : BASIC DATA



TRIAL G5 : ANALYSIS RESULTS

WALL COORDINATES

X	Y
32.00	15.00
39.00	45.00
41.00	45.00
50.00	15.00

GROUND COORDINATES

X	Y	SURCHARGE
41.00	45.00	0.00
56.00	55.00	0.00
56.00	52.00	3000.00
76.00	52.00	0.00
76.00	55.00	0.00
86.00	55.00	20000.00
86.00	55.00	0.00
200.00	55.00	

BACKFILL PROPERTIES

ANGLE OF INTERNAL FRICTION :	0.59
ANGLE OF WALL FRICTION :	0.40
DRY DENSITY :	110.00
SATURATED DENSITY :	110.00
COHESIVE STRENGTH :	0.00
ADHESIVE STRENGTH :	0.00

FOUNDATION PROPERTIES

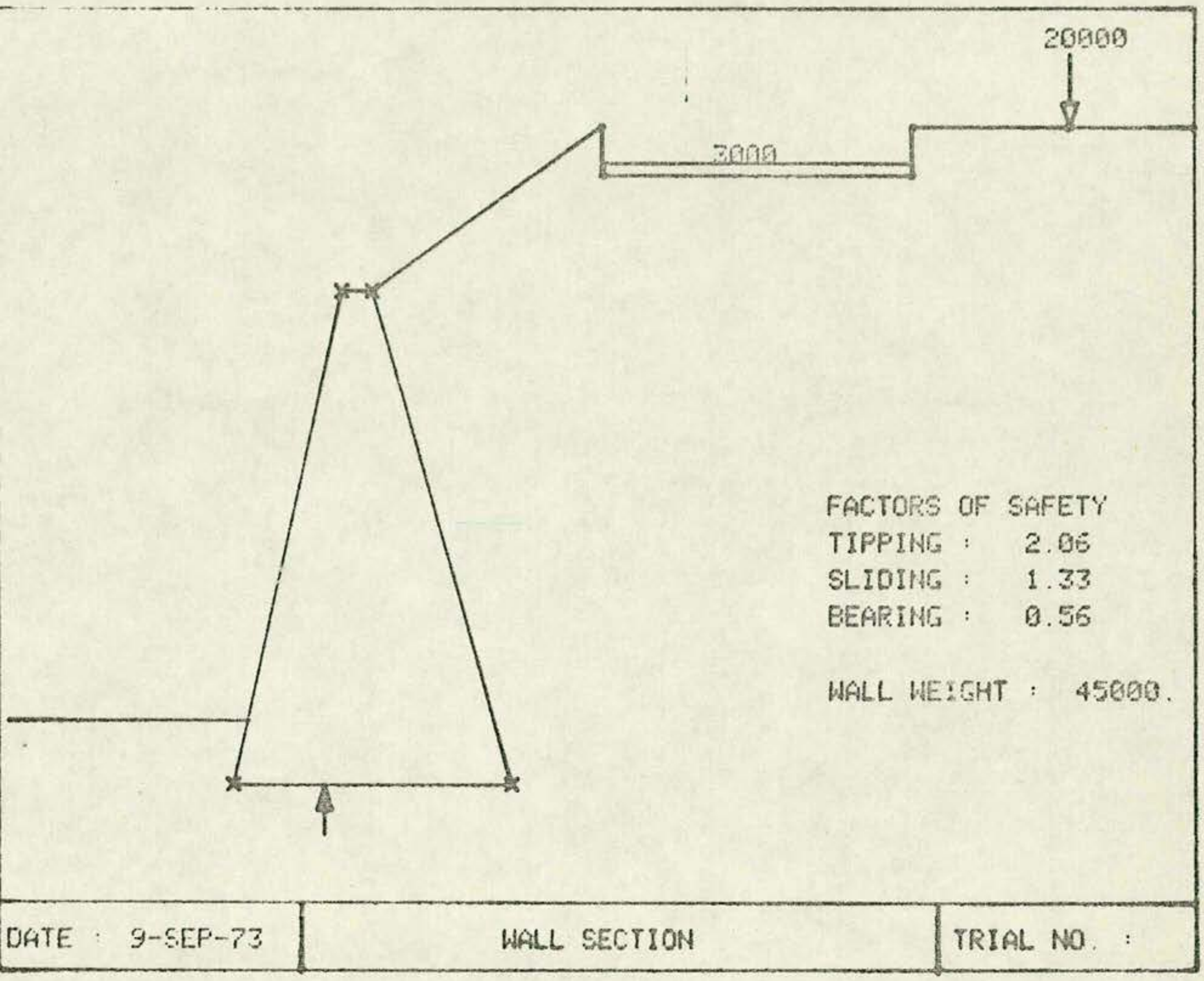
ANGLE OF INTERNAL FRICTION :	0.59
ANGLE OF WALL FRICTION :	0.59
BASE ADHESION :	0.00
BEARING CAPACITY :	5000.00
BEARING MAXIMUM	0.00

FRONT CONDITIONS

X-COORD :	6.00
Y-COORD :	19.00
SLOPE :	0.00
SURCHARGE :	0.00

DATE : 9-SEP-73	BASIC DATA	TRIAL NO. :

TRIAL G6 : BASIC DATA



TRIAL G6 : ANALYSIS RESULTS

WALL COORDINATES

X	Y
36.00	15.00
36.00	17.00
38.00	19.00
38.00	45.00
41.00	45.00
51.92	15.00

GROUND COORDINATES

X	Y	SURCHARGE
41.00	45.00	0.00
241.00	38.60	

BACKFILL PROPERTIES

ANGLE OF INTERNAL FRICTION	:	0.52
ANGLE OF WALL FRICTION	:	0.35
DRY DENSITY	:	110.00
SATURATED DENSITY	:	110.00
COHESIVE STRENGTH	:	0.00
ADHESIVE STRENGTH	:	0.00

FOUNDATION PROPERTIES

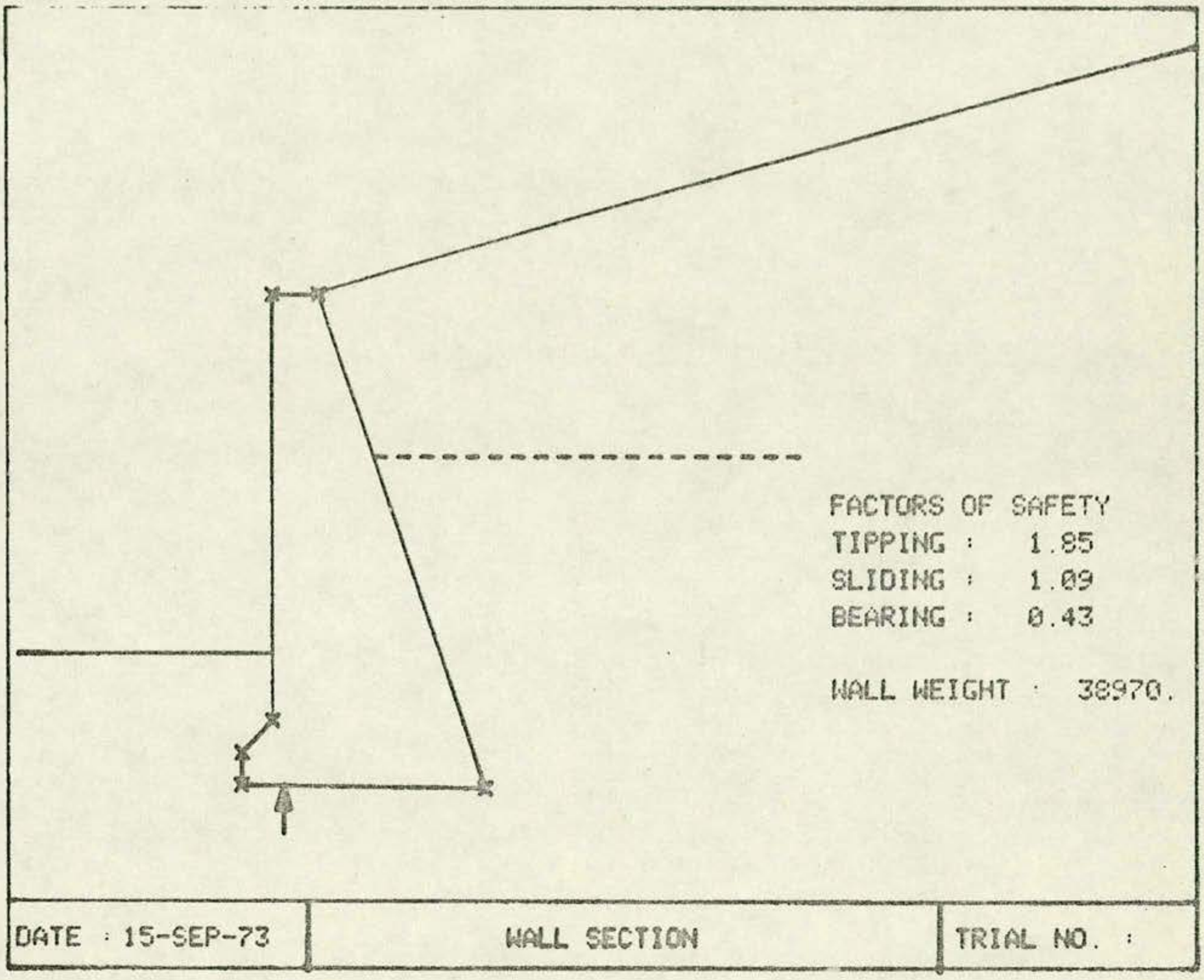
ANGLE OF INTERNAL FRICTION	:	0.52
ANGLE OF WALL FRICTION	:	0.52
BASE ADHESION	:	0.00
BEARING CAPACITY	:	5000.00
BEARING MAXIMUM		0.00

FRONT CONDITIONS

X-COORD	:	6.00
Y-COORD	:	23.00
SLOPE	:	0.00
SURCHARGE	:	0.00

DATE : 15-SEP-73	BASIC DATA	TRIAL NO. :

TRIAL G7 : BASIC DATA



TRIAL G7 : ANALYSIS RESULTS

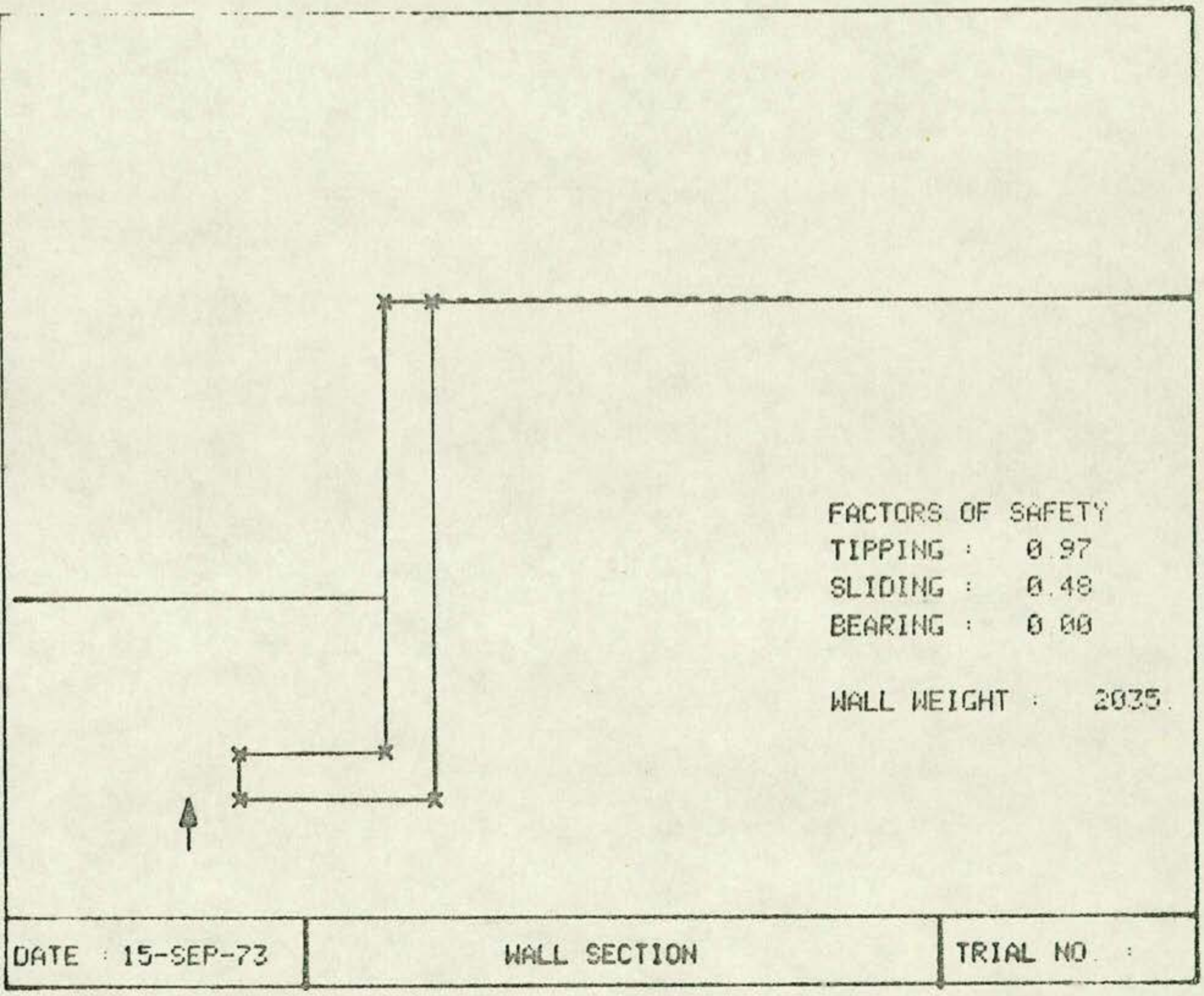
WALL COORDINATES		GROUND COORDINATES		
X	Y	X	Y	SURCHARGE
36.75	35.00	41.00	45.00	0.00
36.75	35.95	241.00	45.00	
39.93	35.97			
39.97	45.00			
41.00	45.00			
41.00	35.00			

BACKFILL PROPERTIES		FRONT CONDITIONS	
ANGLE OF INTERNAL FRICTION :	0.52	X-COORD :	6.00
ANGLE OF WALL FRICTION :	0.35	Y-COORD :	39.00
DRY DENSITY :	110.00	SLOPE :	0.00
SATURATED DENSITY :	130.00	SURCHARGE :	0.00
COHESIVE STRENGTH :	0.00		
ADHESIVE STRENGTH :	0.00		

FOUNDATION PROPERTIES	
ANGLE OF INTERNAL FRICTION :	0.52
ANGLE OF WALL FRICTION :	0.52
BASE ADHESION :	0.00
BEARING CAPACITY :	5000.00
BEARING MAXIMUM	0.00

DATE : 15-SEP-73	BASIC DATA	TRIAL NO. :

TRIAL G8 : BASIC DATA



TRIAL G8 : ANALYSIS RESULTS

WALL COORDINATES

X	Y
37.06	19.94
37.06	21.88
38.87	24.62
39.00	45.00
41.00	45.00
50.77	24.00
50.77	20.00

GROUND COORDINATES

X	Y	SURCHARGE
41.00	45.00	0.00
241.00	98.60	

BACKFILL PROPERTIES

ANGLE OF INTERNAL FRICTION	:	0.52
ANGLE OF WALL FRICTION	:	0.35
DRY DENSITY	:	110.00
SATURATED DENSITY	:	110.00
COHESIVE STRENGTH	:	0.00
ADHESIVE STRENGTH	:	0.00

FRONT CONDITIONS

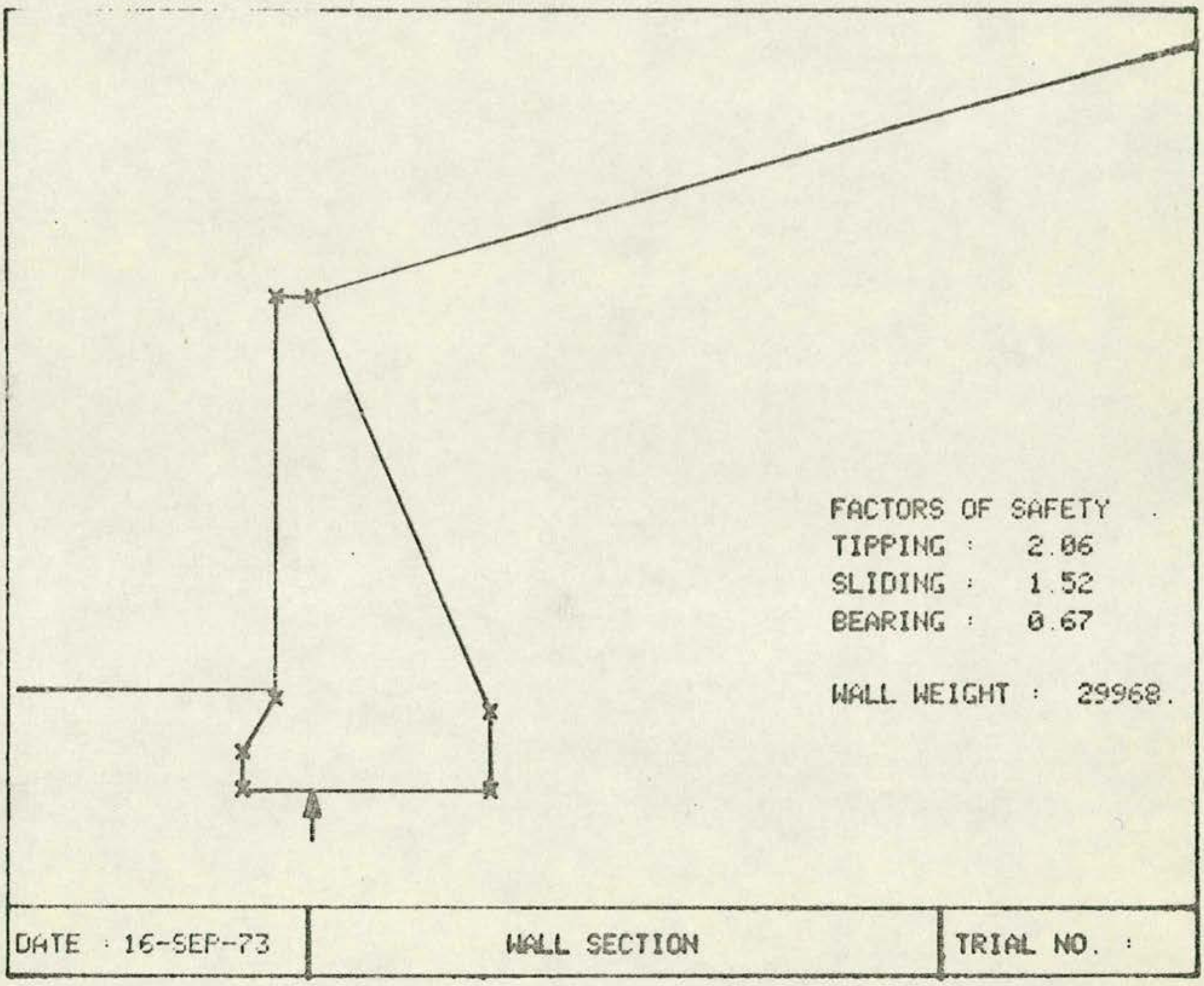
X-COORD	:	6.00
Y-COORD	:	25.00
SLOPE	:	0.00
SURCHARGE	:	0.00

FOUNDATION PROPERTIES

ANGLE OF INTERNAL FRICTION	:	0.52
ANGLE OF WALL FRICTION	:	0.52
BASE ADHESION	:	0.00
BEARING CAPACITY	:	5000.00
BEARING MAXIMUM		0.00

DATE : 16-SEP-73	BASIC DATA	TRIAL NO. :

TRIAL G9 : BASIC DATA



TRIAL G9 : ANALYSIS RESULTS

WALL COORDINATES

X	Y
36.77	23.00
36.77	24.00
37.92	36.00
39.50	45.00
41.00	45.00
46.27	26.00
46.77	26.00
46.77	23.00

GROUND COORDINATES

X	Y	SURCHARGE
41.00	45.00	0.00
241.00	80.26	

BACKFILL PROPERTIES

ANGLE OF INTERNAL FRICTION	:	0.56
ANGLE OF WALL FRICTION	:	0.38
DRY DENSITY	:	110.00
SATURATED DENSITY	:	110.00
COHESIVE STRENGTH	:	0.00
ADHESIVE STRENGTH	:	0.00

FRONT CONDITIONS

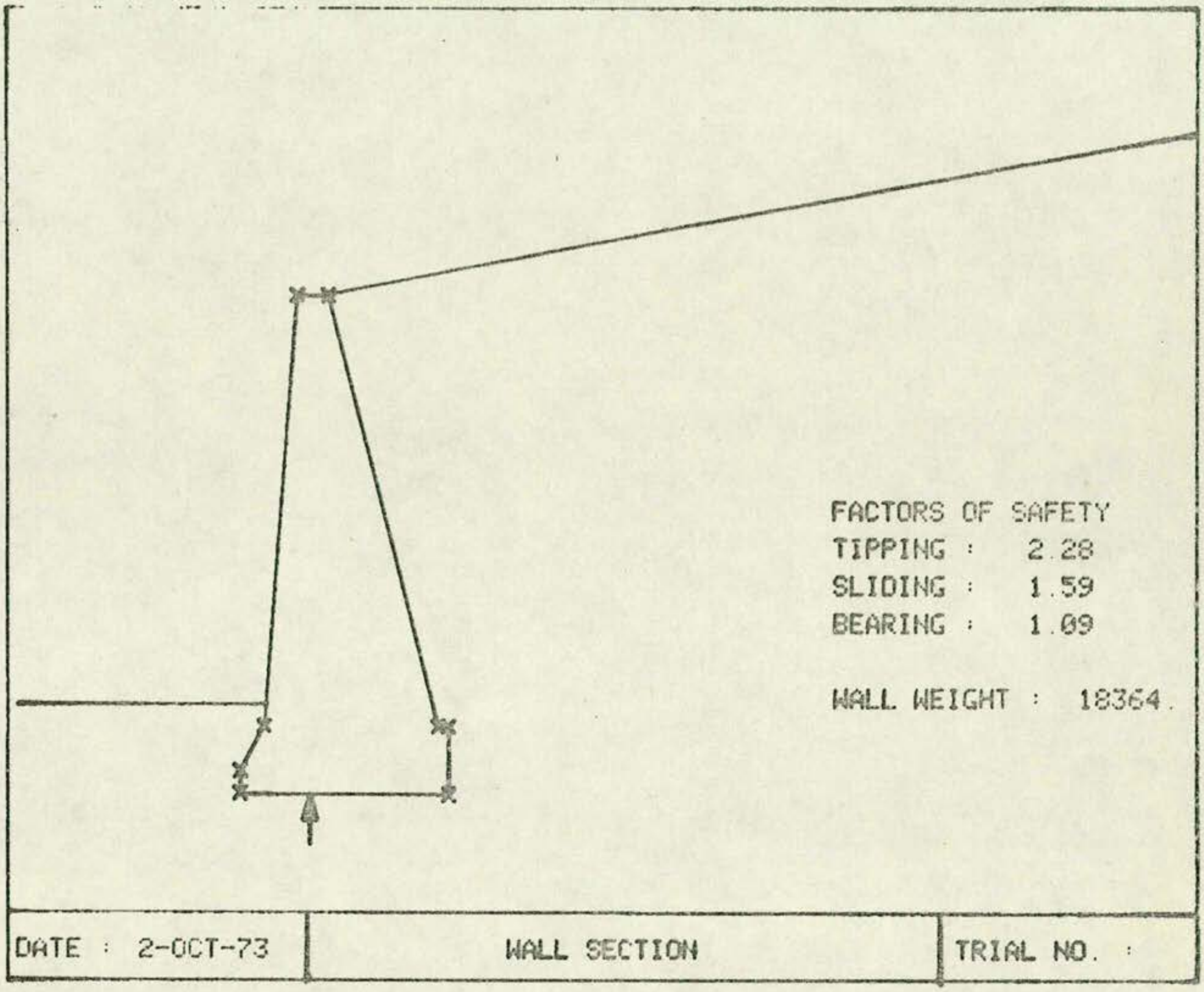
X-COORD	:	6.00
Y-COORD	:	27.00
SLOPE	:	0.00
SURCHARGE	:	0.00

FOUNDATION PROPERTIES

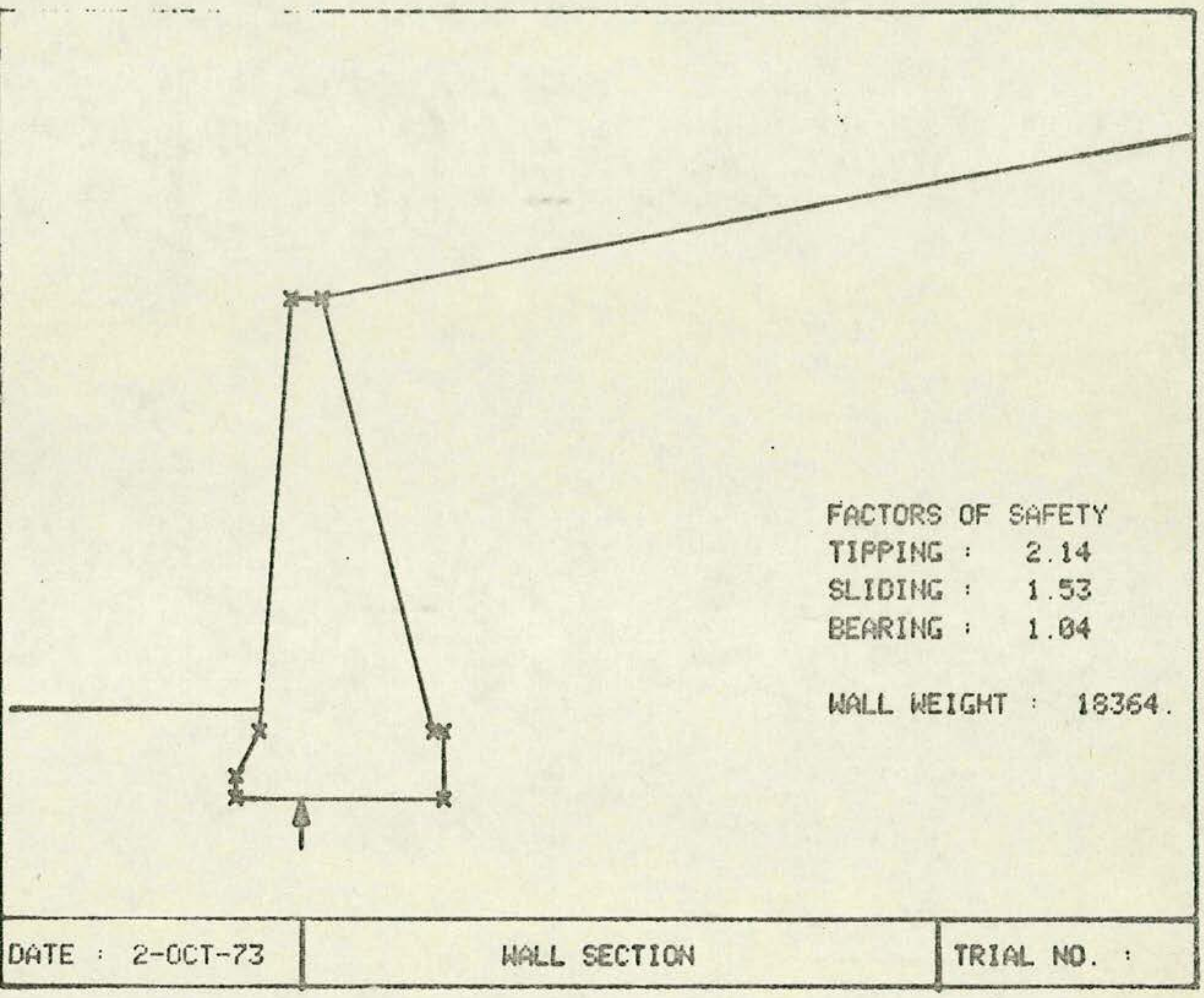
ANGLE OF INTERNAL FRICTION	:	0.41
ANGLE OF WALL FRICTION	:	0.41
BASE ADHESION	:	0.00
BEARING CAPACITY	:	6000.00
BEARING MAXIMUM		0.00

DATE : 2-OCT-73	BASIC DATA	TRIAL NO. :

TRIAL G10 : BASIC DATA



TRIAL G10 : SIMPLE ANALYSIS RESULTS



TRIAL G10 : INCLUDED WEDGE ANALYSIS RESULTS

WALL COORDINATES

X	Y
35.00	20.00
35.00	22.00
38.00	24.00
39.00	45.00
41.00	45.00
48.56	24.00
50.00	24.00
50.00	20.00

GROUND COORDINATES

X	Y	SURCHARGE
41.00	45.00	0.00
241.00	98.60	

BACKFILL PROPERTIES

ANGLE OF INTERNAL FRICTION	:	0.52
ANGLE OF WALL FRICTION	:	0.35
DRY DENSITY	:	110.00
SATURATED DENSITY	:	110.00
COHESIVE STRENGTH	:	0.00
ADHESIVE STRENGTH	:	0.00

FRONT CONDITIONS

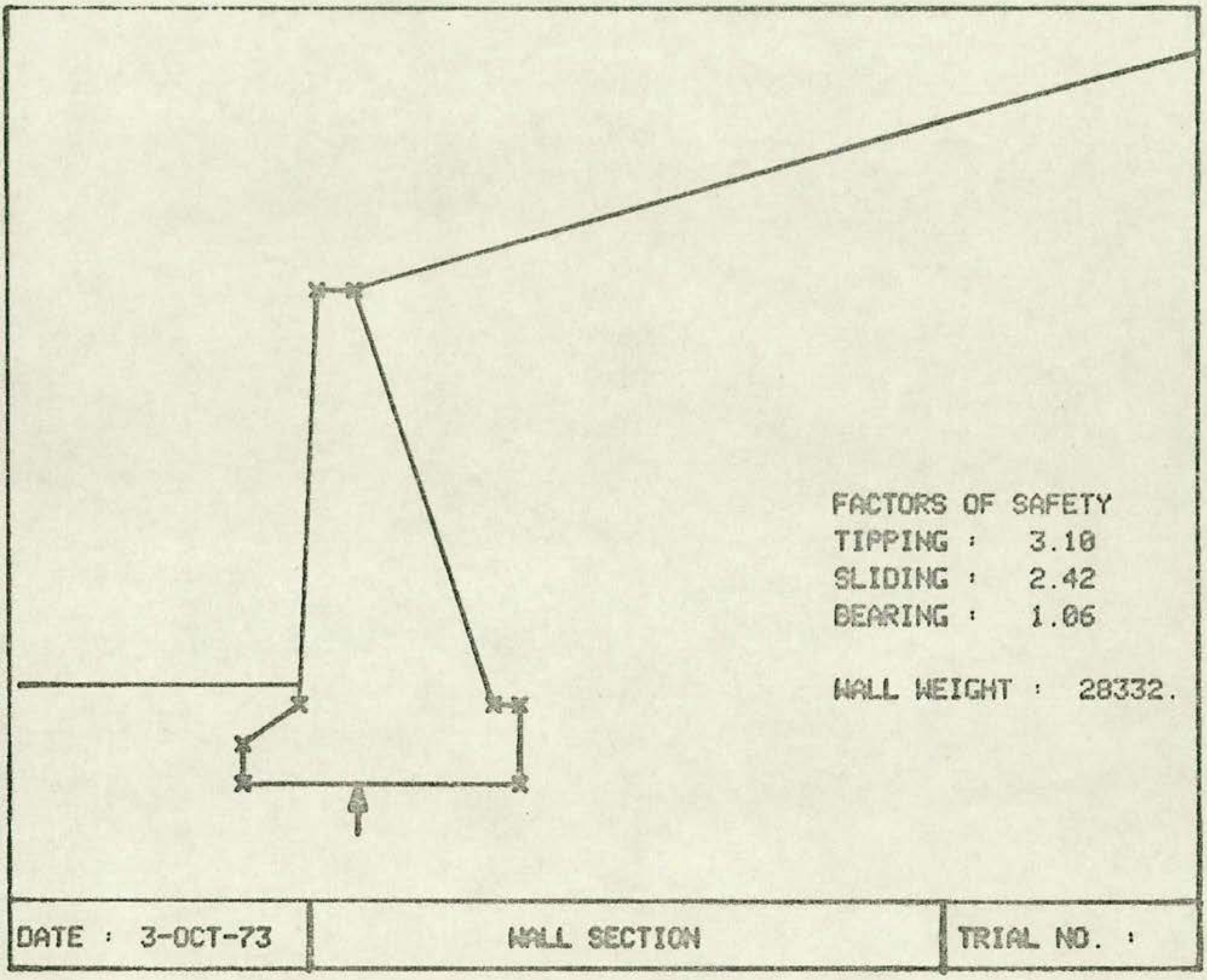
X-COORD	:	6.00
Y-COORD	:	25.00
SLOPE	:	0.00
SURCHARGE	:	0.00

FOUNDATION PROPERTIES

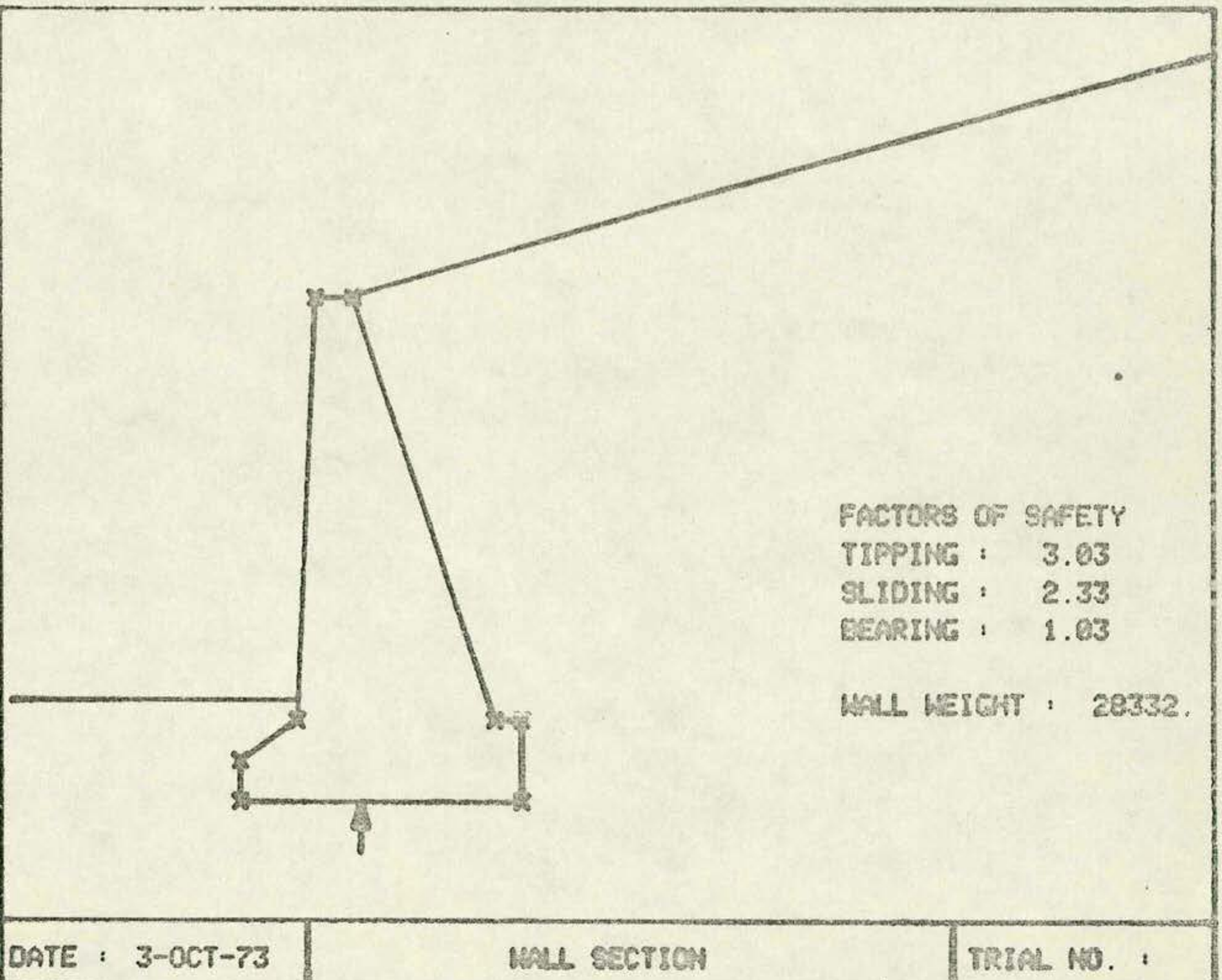
ANGLE OF INTERNAL FRICTION	:	0.61
ANGLE OF WALL FRICTION	:	0.61
BASE ADHESION	:	0.00
BEARING CAPACITY	:	5000.00
BEARING MAXIMUM		0.00

DATE : 3-OCT-73	BASIC DATA	TRIAL NO. :

TRIAL G11 : BASIC DATA



TRIAL G11 : SIMPLE ANALYSIS RESULTS



TRIAL G11 : INCLUDED WEDGE ANALYSIS RESULTS

WALL COORDINATES

X	Y
27.00	20.00
27.00	22.00
28.00	23.00
39.00	45.00
41.00	45.00
44.50	24.00
47.50	24.00
47.50	20.00

GROUND COORDINATES

X	Y	SURCHARGE
41.00	45.00	0.00
241.00	59.00	

BACKFILL PROPERTIES

ANGLE OF INTERNAL FRICTION	:	0.52
ANGLE OF WALL FRICTION	:	0.35
DRY DENSITY	:	110.00
SATURATED DENSITY	:	110.00
COHESIVE STRENGTH	:	0.00
ADHESIVE STRENGTH	:	0.00

FRONT CONDITIONS

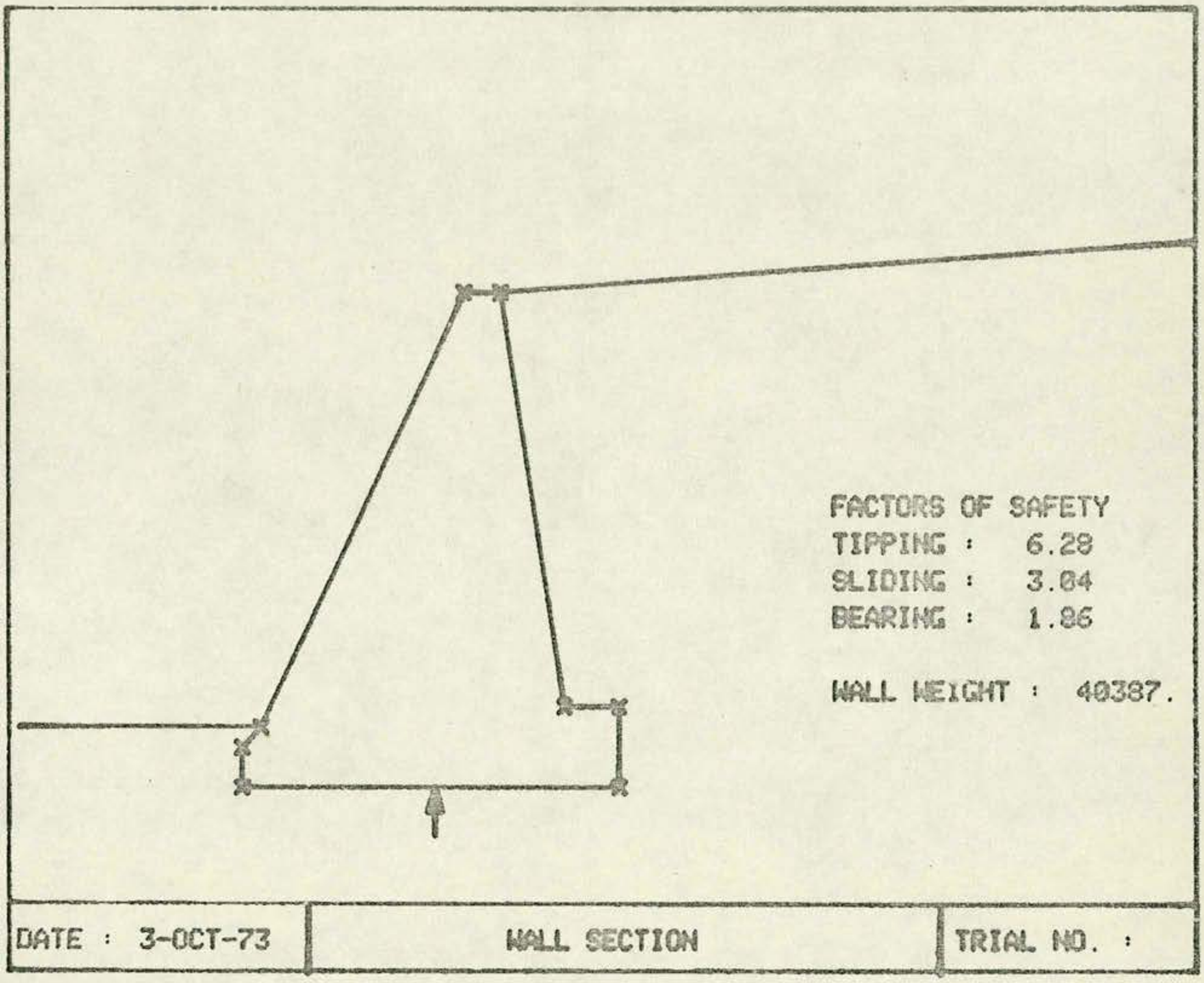
X-COORD	:	6.00
Y-COORD	:	23.00
SLOPE	:	0.00
SURCHARGE	:	0.00

FOUNDATION PROPERTIES

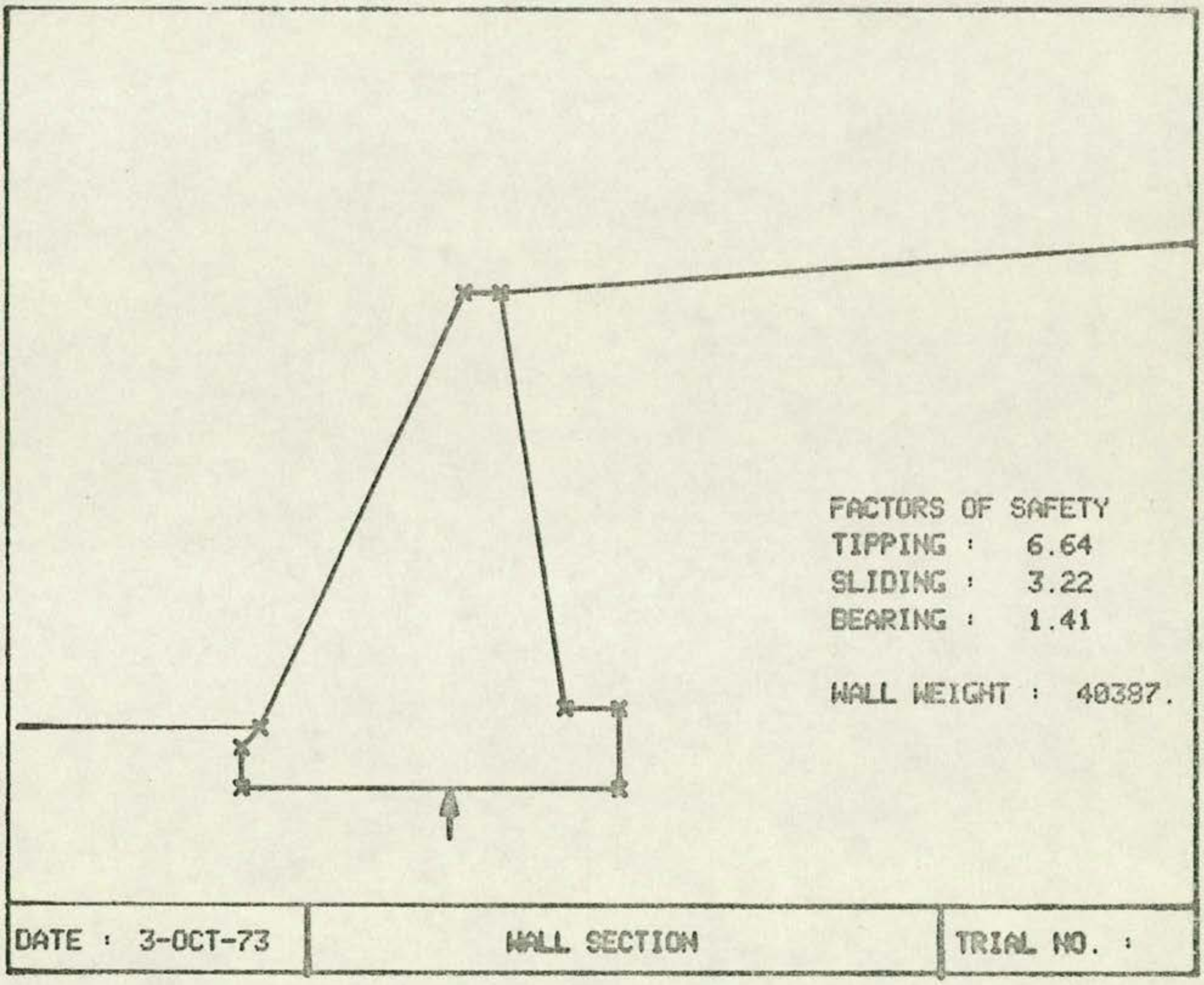
ANGLE OF INTERNAL FRICTION	:	0.61
ANGLE OF WALL FRICTION	:	0.61
BASE ADHESION	:	0.00
BEARING CAPACITY	:	5000.00
BEARING MAXIMUM		0.00

DATE : 3-OCT-73	BASIC DATA	TRIAL NO. :

TRIAL G12 : BASIC DATA



TRIAL G12 : SIMPLE ANALYSIS RESULTS



TRIAL G12 : INCLUDED WEDGE ANALYSIS RESULTS

WALL COORDINATES

X	Y
35.10	5.00
36.60	45.00
41.00	45.00
58.80	5.00

GROUND COORDINATES

X	Y	SURCHARGE
41.00	45.00	0.00
241.00	98.60	

BACKFILL PROPERTIES

ANGLE OF INTERNAL FRICTION	:	0.17
ANGLE OF WALL FRICTION	:	0.12
DRY DENSITY	:	100.00
SATURATED DENSITY	:	100.00
COHESIVE STRENGTH	:	600.00
ADHESIVE STRENGTH	:	400.00

FOUNDATION PROPERTIES

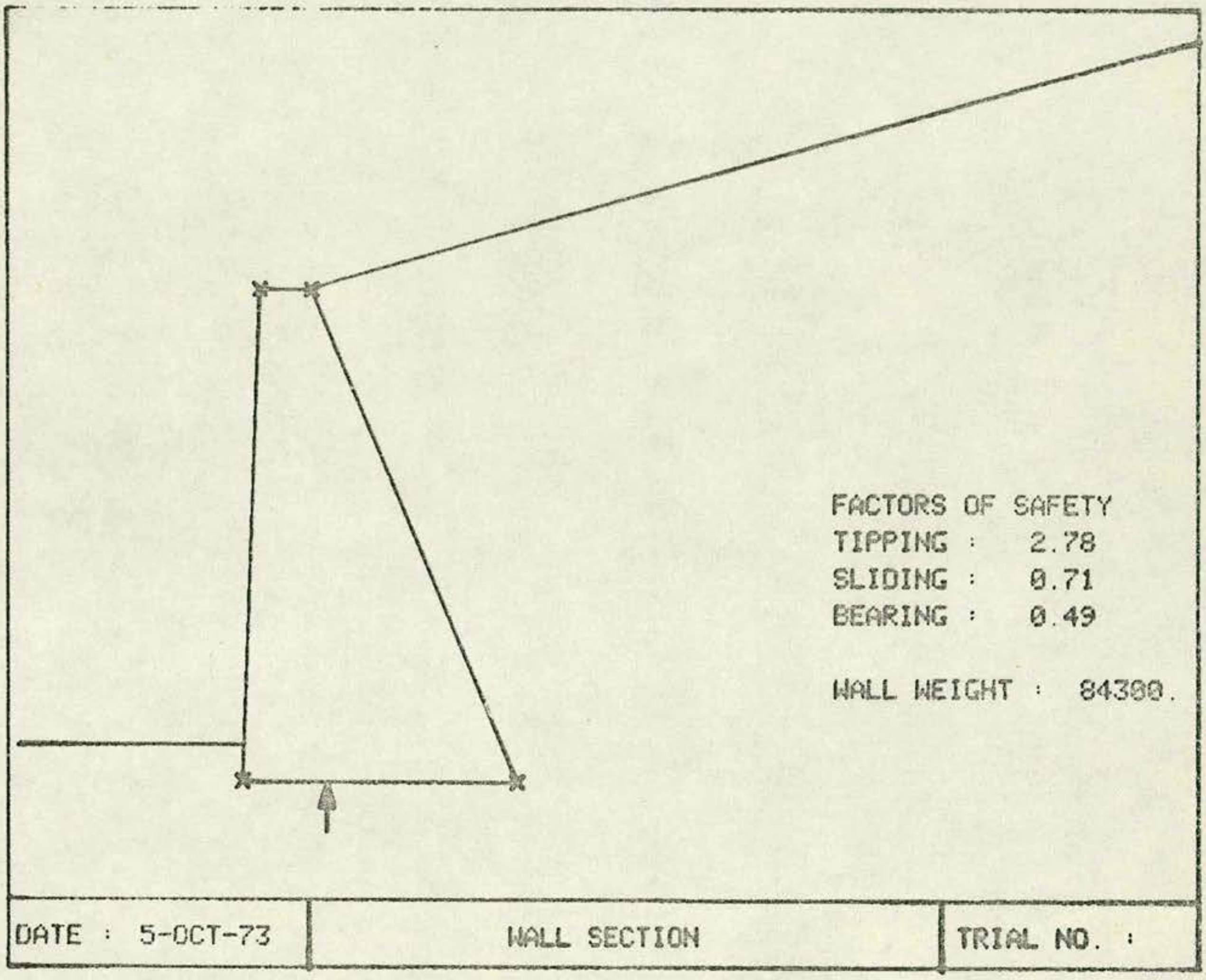
ANGLE OF INTERNAL FRICTION	:	0.17
ANGLE OF WALL FRICTION	:	0.17
BASE ADHESION	:	600.00
BEARING CAPACITY	:	5000.00
BEARING MAXIMUM		0.00

FRONT CONDITIONS

X-COORD	:	6.00
Y-COORD	:	8.00
SLOPE	:	0.00
SURCHARGE	:	0.00

DATE : 5-OCT-73	BASIC DATA	TRIAL NO. :

TRIAL G13 : BASIC DATA



TRIAL G13 : ANALYSIS RESULTS

WALL COORDINATES

X	Y
31.00	15.00
31.00	17.00
32.00	18.00
39.00	45.00
41.00	45.00
51.00	15.00

GROUND COORDINATES

X	Y	SURCHARGE
41.00	45.00	0.00
49.00	50.00	0.00
60.00	48.50	0.00
71.00	55.00	0.00
85.00	57.00	0.00
139.00	33.00	

BACKFILL PROPERTIES

ANGLE OF INTERNAL FRICTION :	0.11
ANGLE OF WALL FRICTION :	0.07
DRY DENSITY :	100.00
SATURATED DENSITY :	100.00
COHESIVE STRENGTH :	400.00
ADHESIVE STRENGTH :	267.00

FRONT CONDITIONS

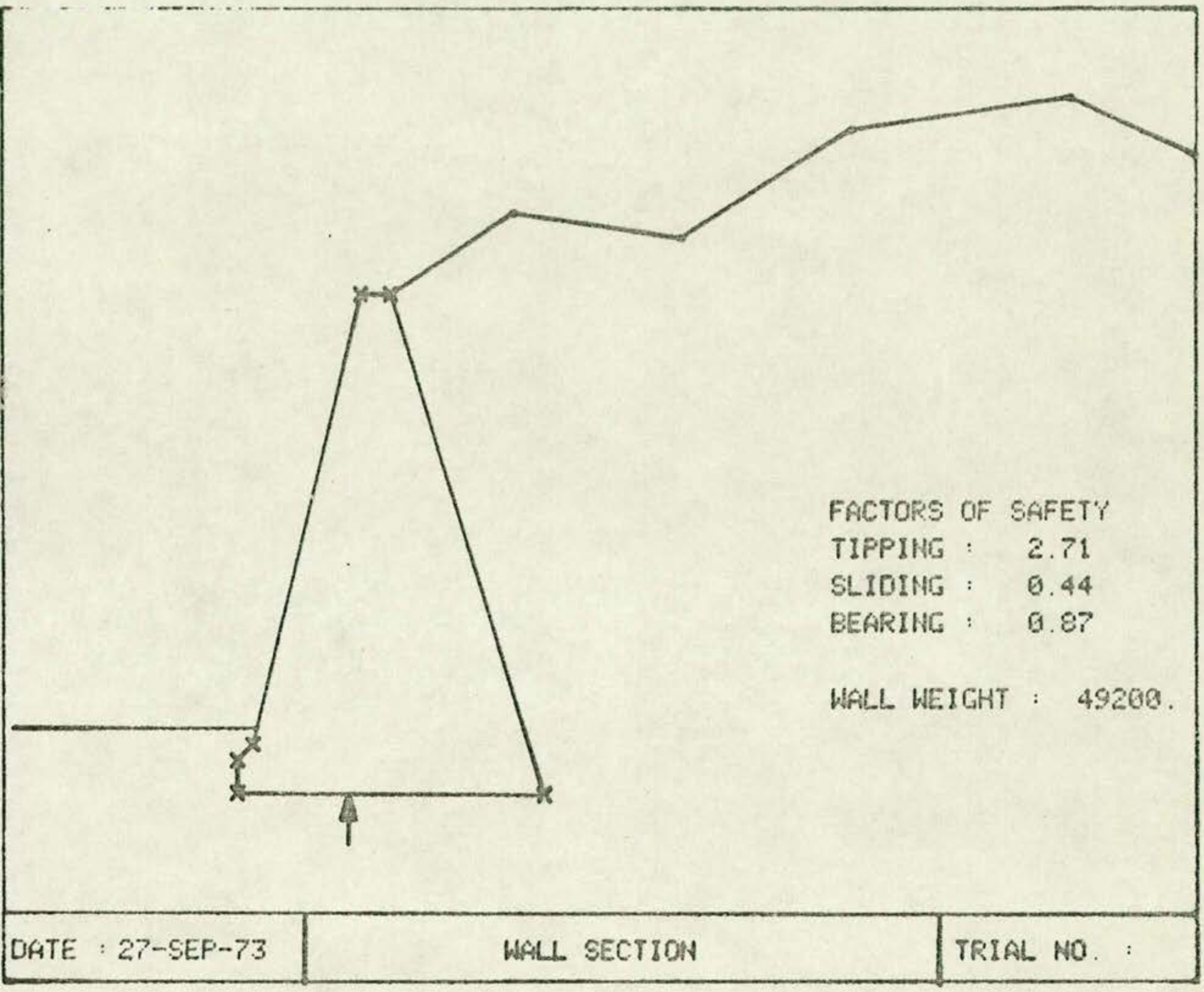
X-COORD :	6.00
Y-COORD :	19.00
SLOPE :	0.00
SURCHARGE :	0.00

FOUNDATION PROPERTIES

ANGLE OF INTERNAL FRICTION :	0.11
ANGLE OF WALL FRICTION :	0.11
BASE ADHESION :	400.00
BEARING CAPACITY :	5000.00
BEARING MAXIMUM	0.00

DATE : 27-SEP-73	BASIC DATA	TRIAL NO. :

TRIAL G14 : BASIC DATA



TRIAL G14 : ANALYSIS RESULTS

WALL COORDINATES

X	Y
35.00	15.00
35.00	17.00
36.00	18.00
38.00	45.00
41.00	45.00
53.00	15.00

GROUND COORDINATES

X	Y	SURCHARGE
41.00	45.00	0.00
59.00	56.00	0.00
64.00	56.00	10000.00
64.00	56.00	0.00
70.00	56.00	0.00
70.00	51.00	2000.00
90.00	51.00	0.00
90.00	56.00	0.00
98.00	56.00	0.00
198.00	142.50	

BACKFILL PROPERTIES

ANGLE OF INTERNAL FRICTION	:	0.11
ANGLE OF WALL FRICTION	:	0.07
DRY DENSITY	:	100.00
SATURATED DENSITY	:	100.00
COHESIVE STRENGTH	:	400.00
ADHESIVE STRENGTH	:	267.00

FRONT CONDITIONS

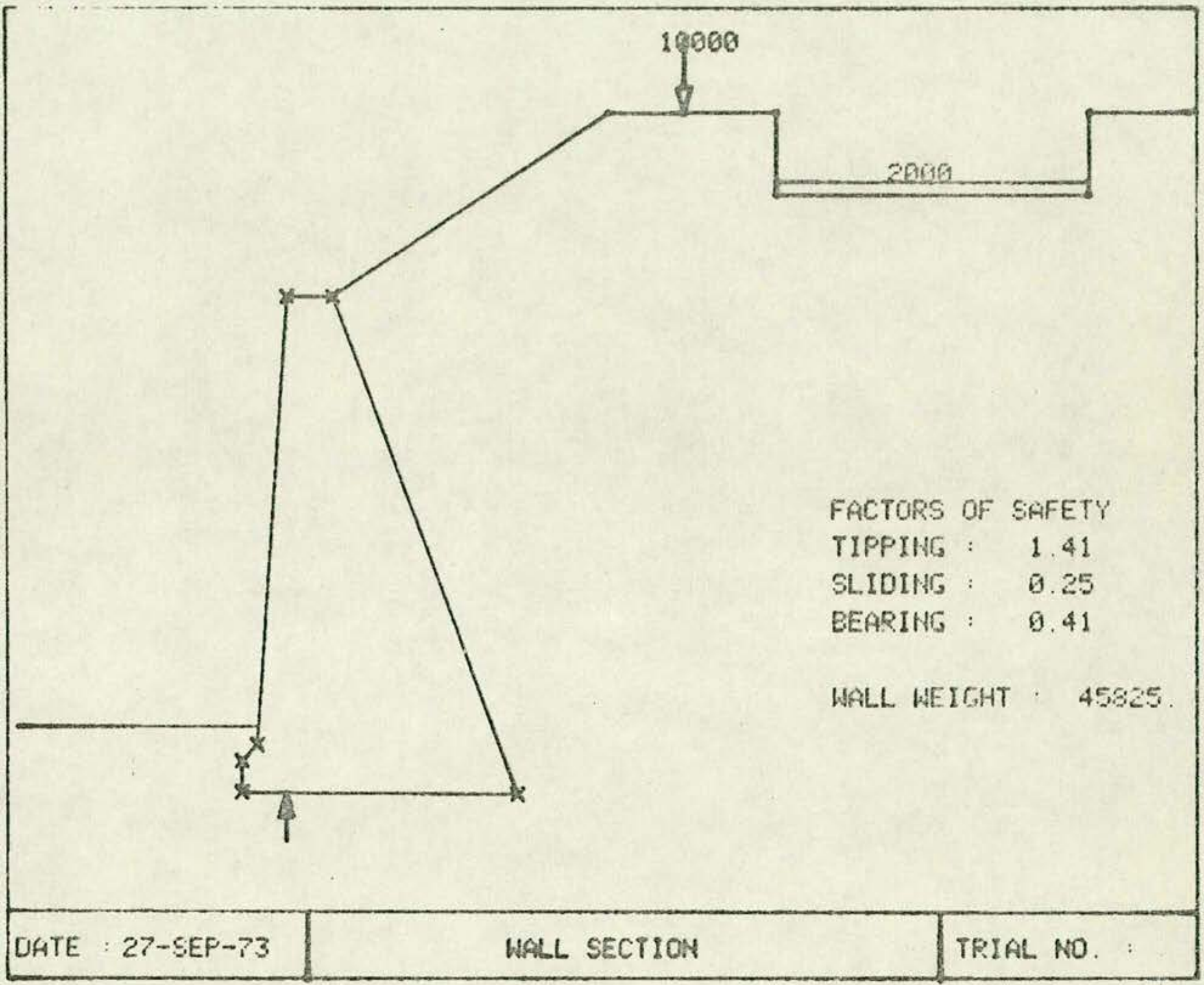
X-COORD	:	6.00
Y-COORD	:	19.00
SLOPE	:	0.00
SURCHARGE	:	0.00

FOUNDATION PROPERTIES

ANGLE OF INTERNAL FRICTION	:	0.11
ANGLE OF WALL FRICTION	:	0.11
BASE ADHESION	:	400.00
BEARING CAPACITY	:	5000.00
BEARING MAXIMUM		0.00

DATE : 27-SEP-73	BASIC DATA	TRIAL NO. :

TRIAL G15 : BASIC DATA



TRIAL G15 : ANALYSIS RESULTS

APPENDIX 11 : CANTILEVER WALL TRIALS

WALL COORDINATES

X	Y
36.63	17.00
36.63	19.00
39.63	19.00
40.17	45.00
41.00	45.00
41.00	19.00
50.00	19.00
50.00	17.00

GROUND COORDINATES

X	Y	SURCHARGE
41.00	45.00	0.00
241.00	80.26	

BACKFILL PROPERTIES

ANGLE OF INTERNAL FRICTION	:	0.59
ANGLE OF WALL FRICTION	:	0.40
DRY DENSITY	:	115.00
SATURATED DENSITY	:	115.00
COHESIVE STRENGTH	:	0.00
ADHESIVE STRENGTH	:	0.00

FRONT CONDITIONS

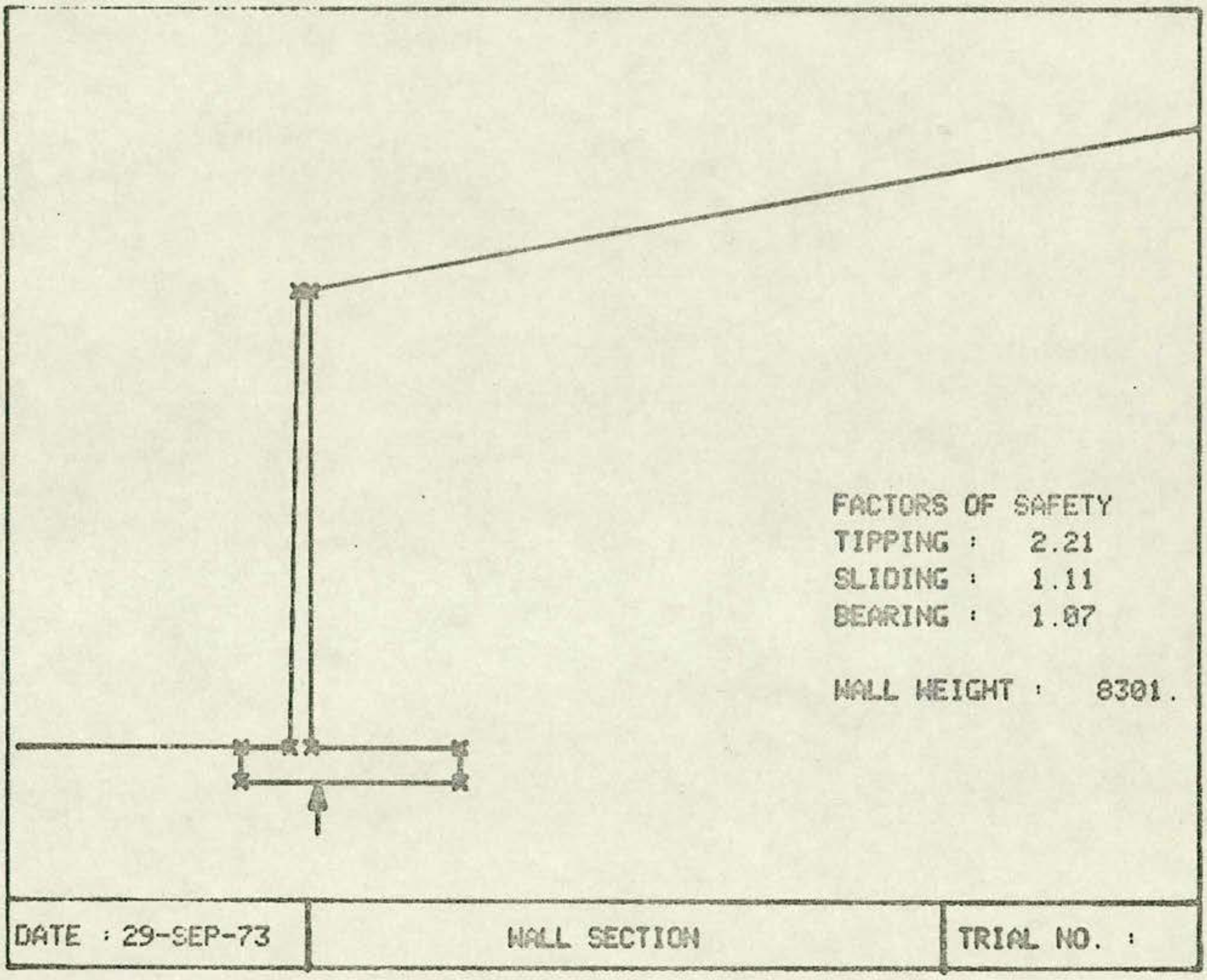
X-COORD	:	6.00
Y-COORD	:	19.05
SLOPE	:	0.00
SURCHARGE	:	0.00

FOUNDATION PROPERTIES

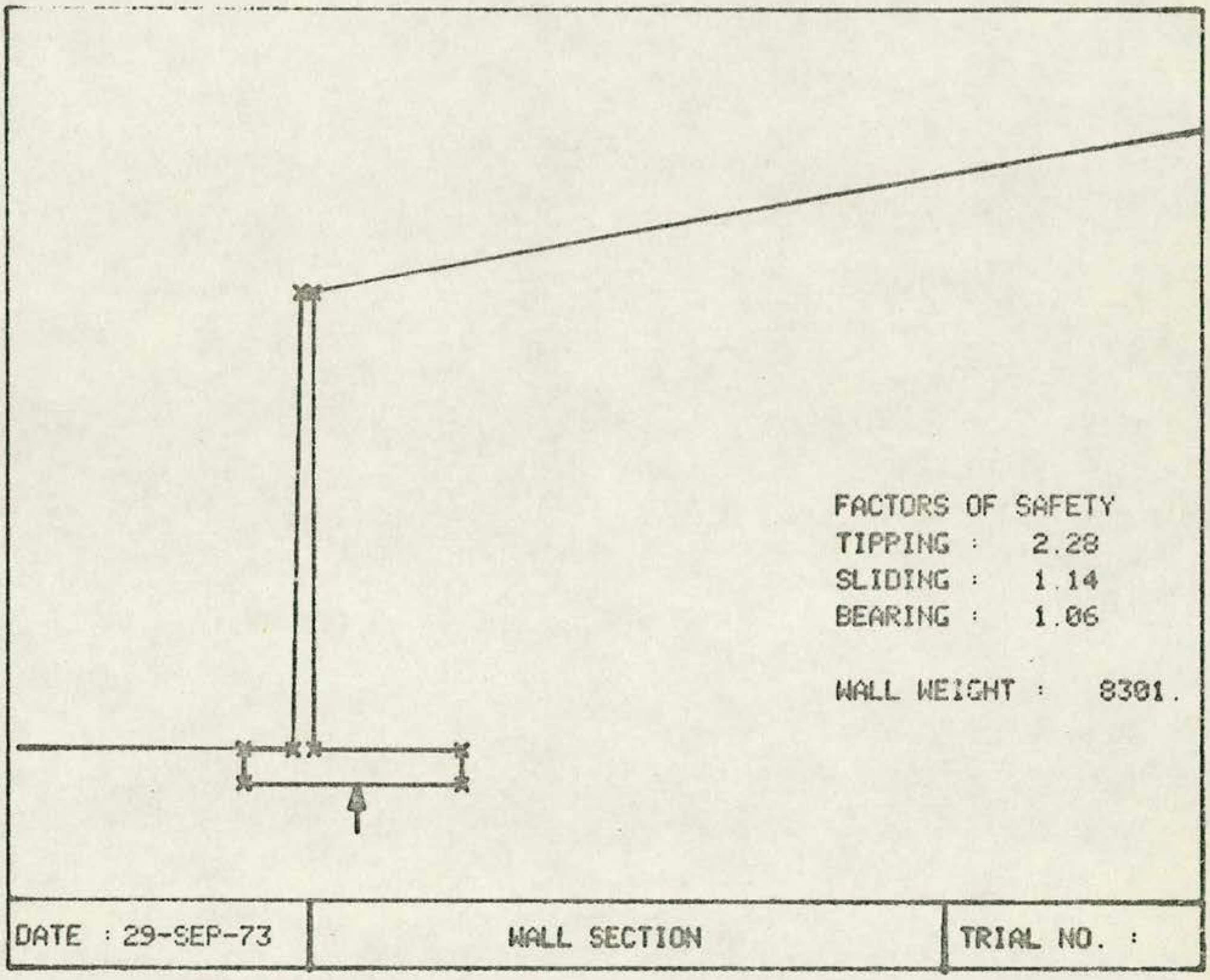
ANGLE OF INTERNAL FRICTION	:	0.40
ANGLE OF WALL FRICTION	:	0.40
BASE ADHESION	:	0.00
BEARING CAPACITY	:	6000.00
BEARING MAXIMUM		0.00

DATE : 29-SEP-73	BASIC DATA	TRIAL NO. :

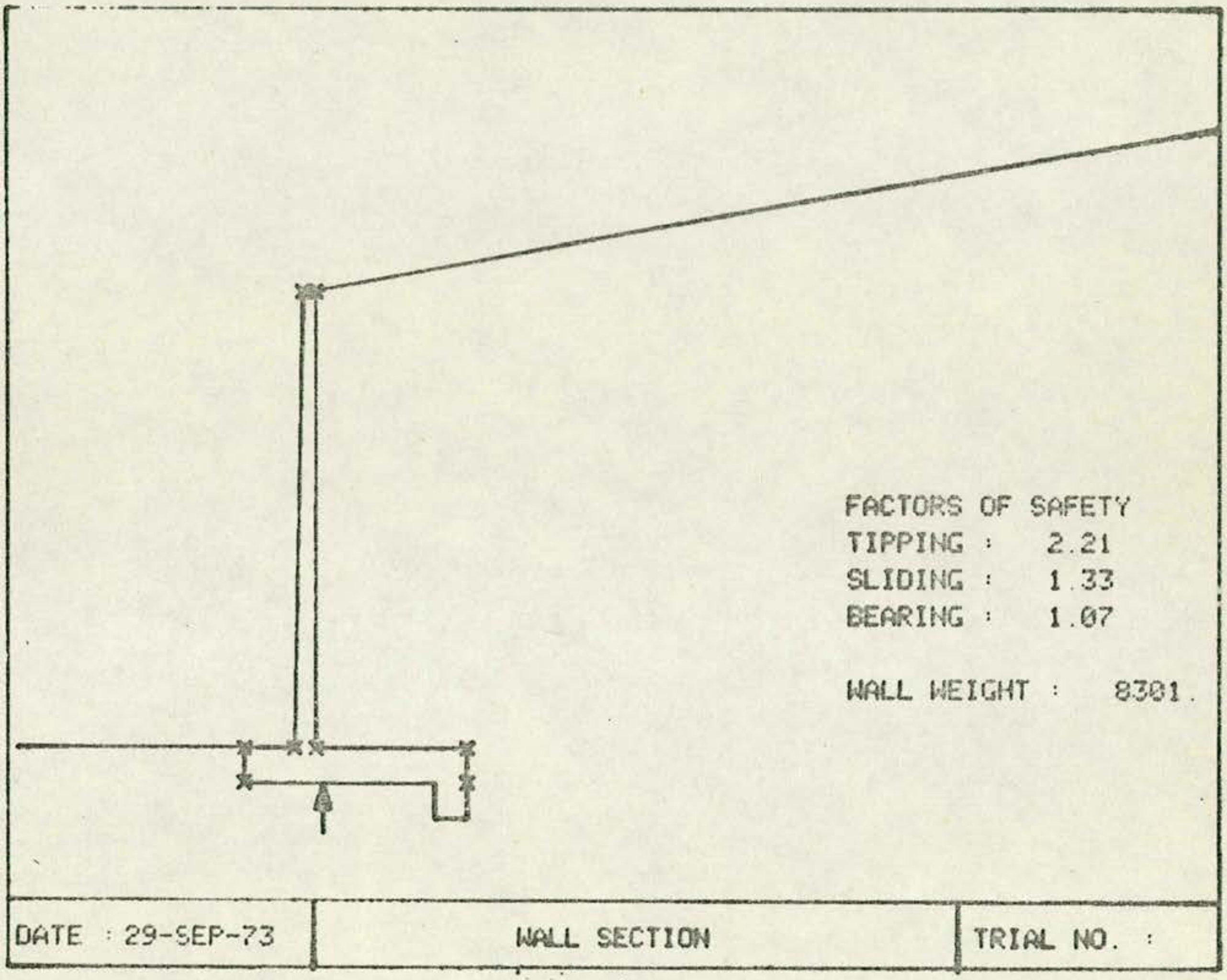
TRIAL C1 : BASIC DATA



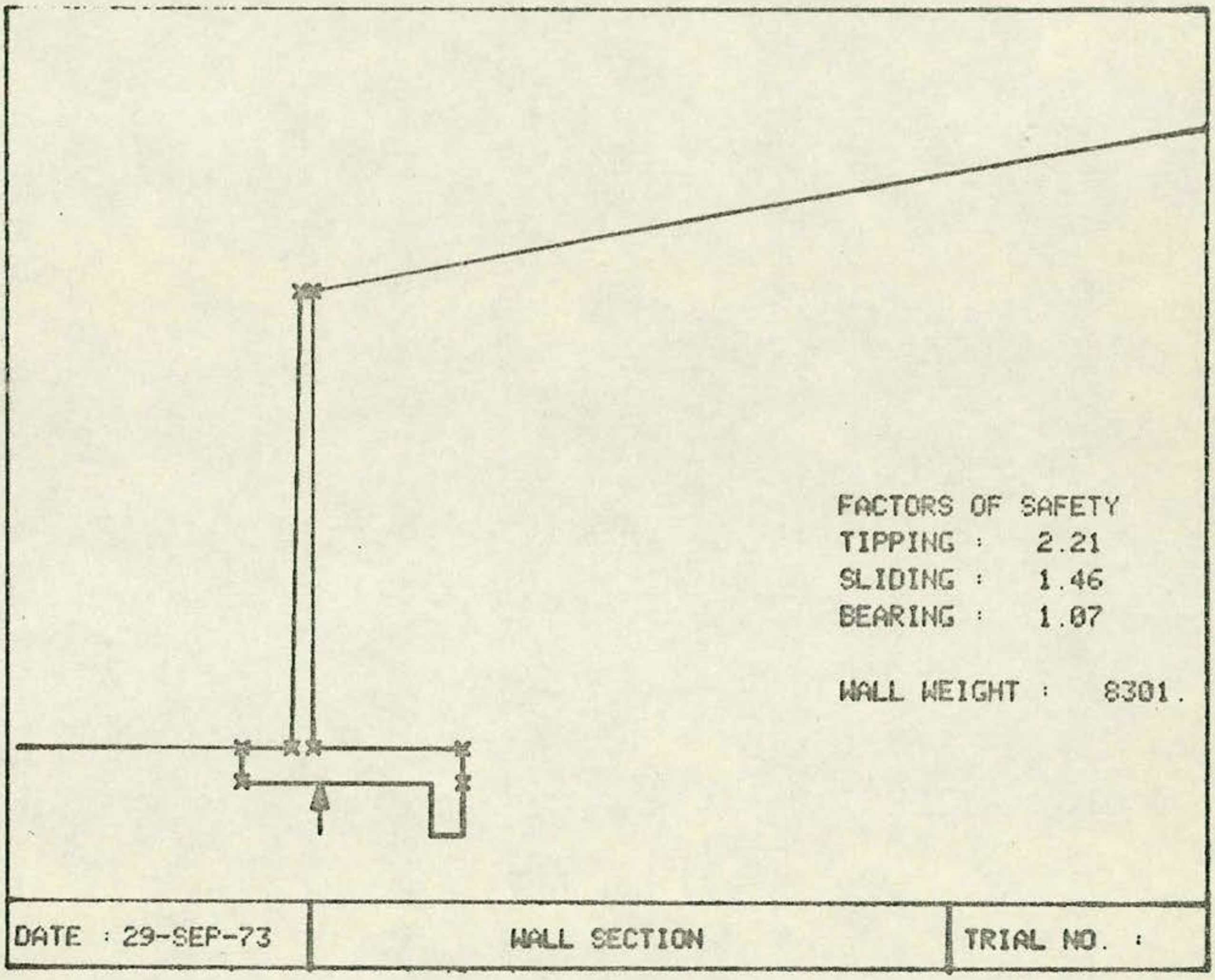
TRIAL C1 : SIMPLE ANALYSIS RESULTS NO KEY



TRIAL C1 : INCLUDED WEDGE ANALYSIS RESULTS NO KEY



TRIAL C1 : SIMPLE ANALYSIS RESULTS 2'00" KEY



TRIAL C1 : SIMPLE ANALYSIS RESULTS 3'00" KEY

WALL COORDINATES	
X	Y
35.67	25.00
35.67	26.00
39.67	26.00
40.33	45.00
41.00	45.00
41.87	26.00
47.67	26.00
47.67	25.00

GROUND COORDINATES		
X	Y	SURCHARGE
41.00	45.00	0.00
241.00	45.00	

BACKFILL PROPERTIES

ANGLE OF INTERNAL FRICTION	:	0.52
ANGLE OF WALL FRICTION	:	0.61
DRY DENSITY	:	120.00
SATURATED DENSITY	:	120.00
COHESIVE STRENGTH	:	0.00
ADHESIVE STRENGTH	:	0.00

FOUNDATION PROPERTIES

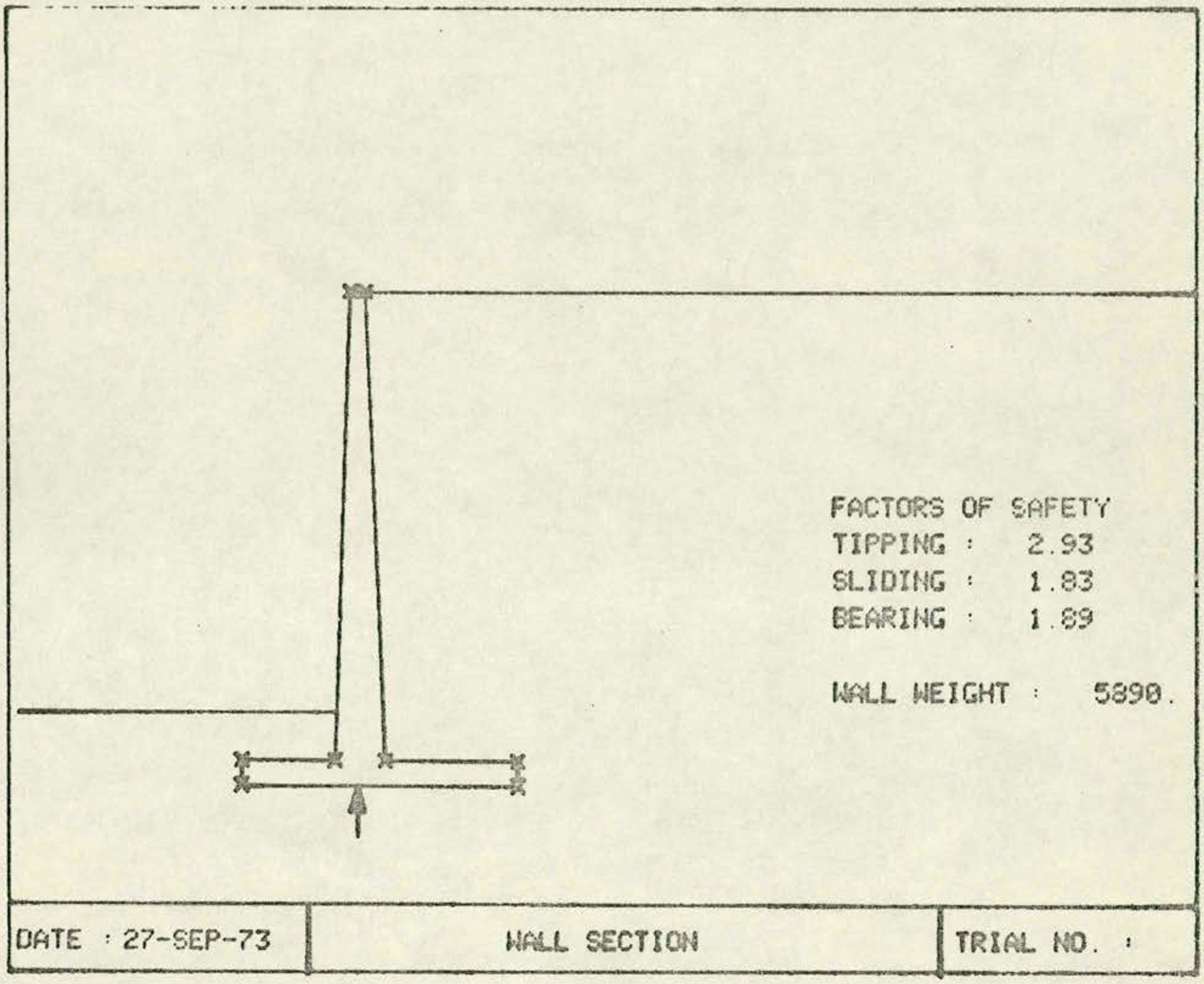
ANGLE OF INTERNAL FRICTION	:	0.61
ANGLE OF WALL FRICTION	:	0.61
BASE ADHESION	:	0.00
BEARING CAPACITY	:	5000.00
BEARING MAXIMUM		0.00

FRONT CONDITIONS

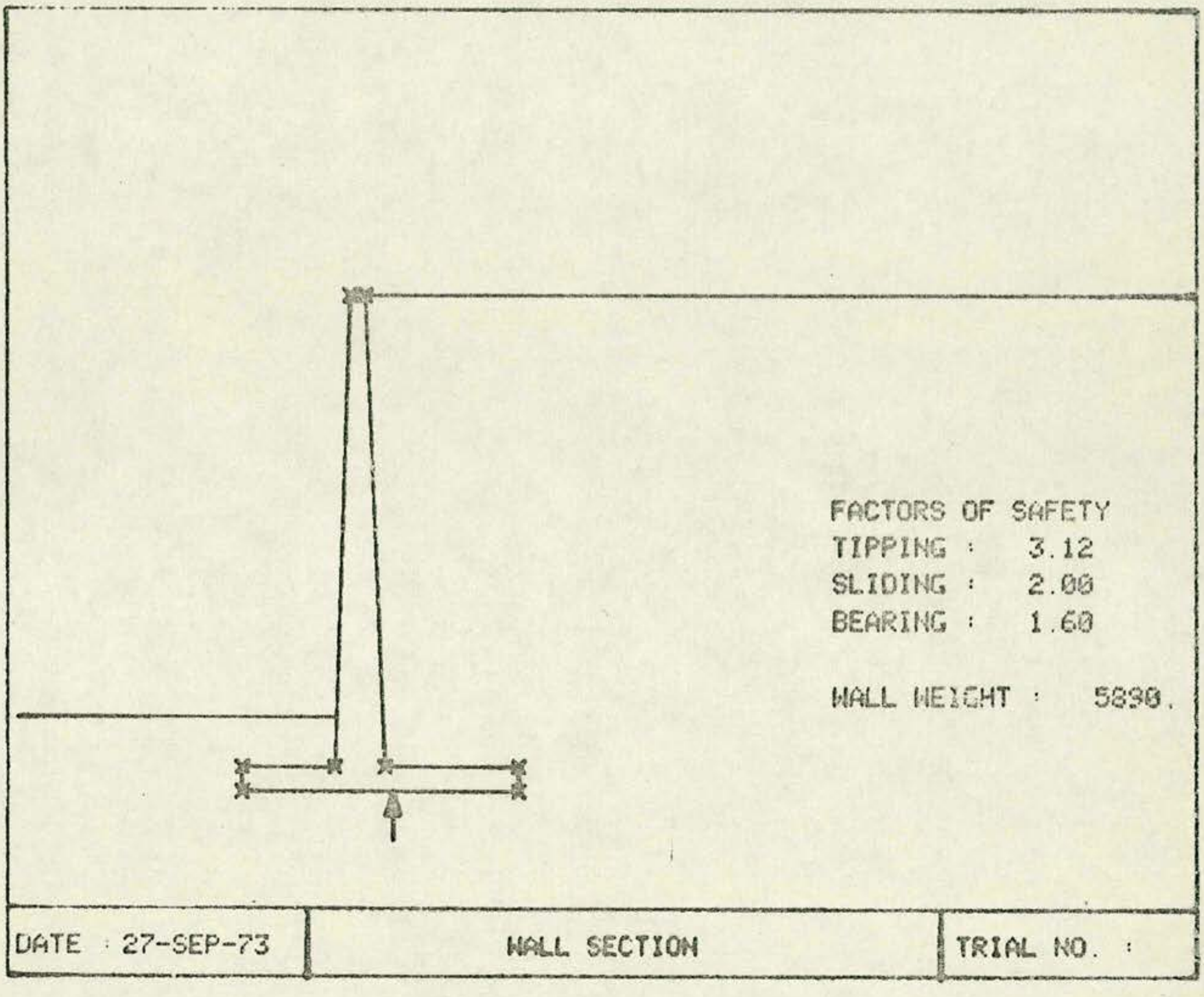
X-COORD	:	6.00
Y-COORD	:	28.00
SLOPE	:	0.00
SURCHARGE	:	0.00

DATE : 27-SEP-73	BASIC DATA	TRIAL NO. :

TRIAL C2 : BASIC DATA



TRIAL C2 : SIMPLE ANALYSIS RESULTS



TRIAL C2 : INCLUDED WEDGE ANALYSIS RESULTS

WALL COORDINATES

X	Y
34.00	20.00
34.00	22.00
39.00	22.00
40.00	45.00
41.00	45.00
41.00	22.00
49.00	22.00
49.00	20.00

GROUND COORDINATES

X	Y	SURCHARGE
41.00	45.00	0.00
241.00	98.60	

BACKFILL PROPERTIES

ANGLE OF INTERNAL FRICTION	:	0.52
ANGLE OF WALL FRICTION	:	0.26
DRY DENSITY	:	110.00
SATURATED DENSITY	:	110.00
COHESIVE STRENGTH	:	0.00
ADHESIVE STRENGTH	:	0.00

FRONT CONDITIONS

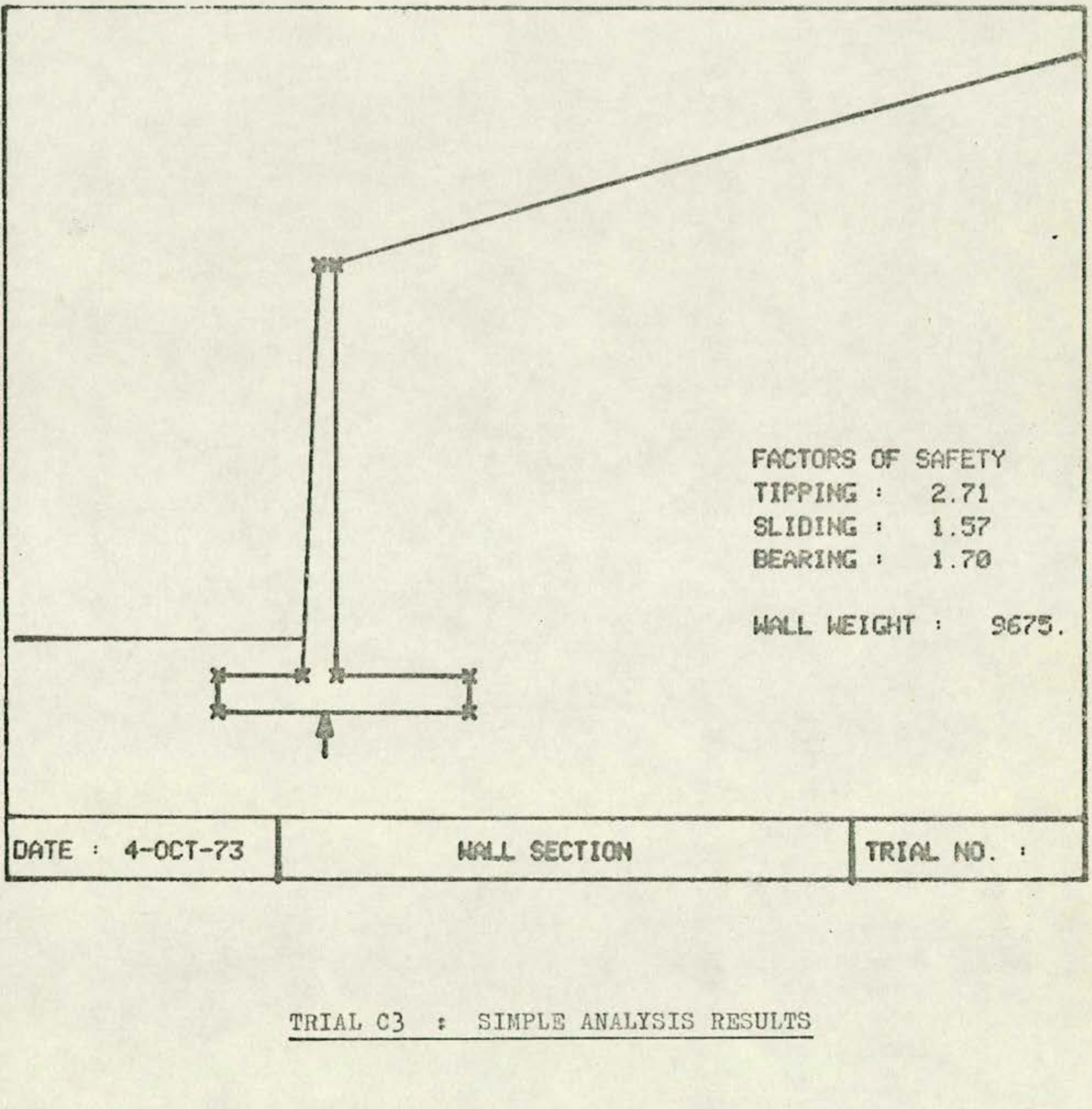
X-COORD	:	6.00
Y-COORD	:	24.00
SLOPE	:	0.00
SURCHARGE	:	0.00

FOUNDATION PROPERTIES

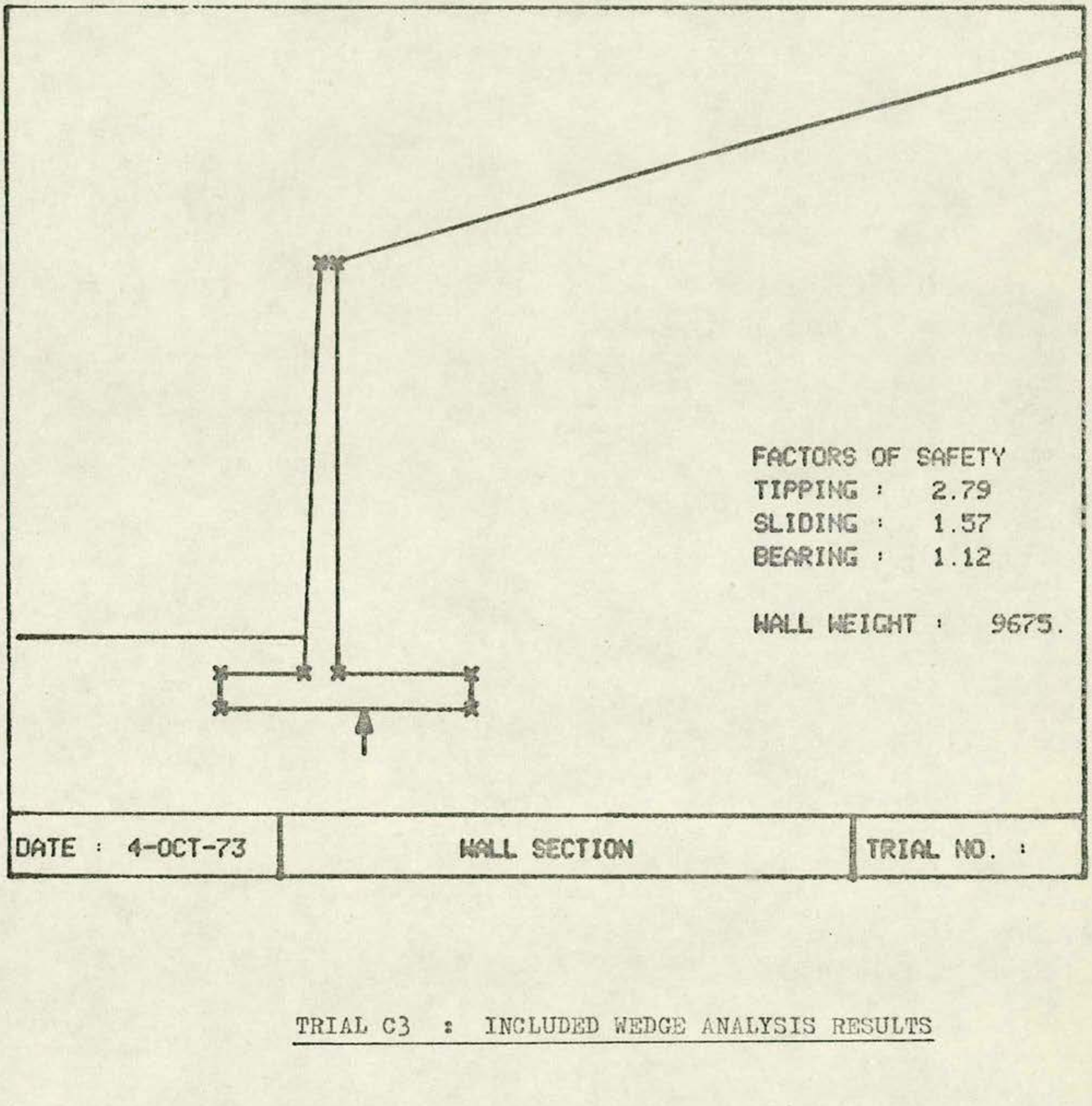
ANGLE OF INTERNAL FRICTION	:	0.52
ANGLE OF WALL FRICTION	:	0.52
BASE ADHESION	:	0.00
BEARING CAPACITY	:	6000.00
BEARING MAXIMUM		0.00

DATE : 4-OCT-73	BASIC DATA	TRIAL NO. :

TRIAL C3 : BASIC DATA



TRIAL C3 : SIMPLE ANALYSIS RESULTS



TRIAL C3 : INCLUDED WEDGE ANALYSIS RESULTS

WALL COORDINATES

X	Y
37.50	25.00
37.50	26.75
39.25	26.75
39.62	45.00
40.37	45.00
41.00	26.75
47.50	26.75
47.50	25.00

GROUND COORDINATES

X	Y	SURCHARGE
40.37	45.00	0.00
47.25	45.00	220.00
241.00	45.00	

BACKFILL PROPERTIES

ANGLE OF INTERNAL FRICTION	:	0.59
ANGLE OF WALL FRICTION	:	0.38
DRY DENSITY	:	110.00
SATURATED DENSITY	:	110.00
COHESIVE STRENGTH	:	0.00
ADHESIVE STRENGTH	:	0.00

FRONT CONDITIONS

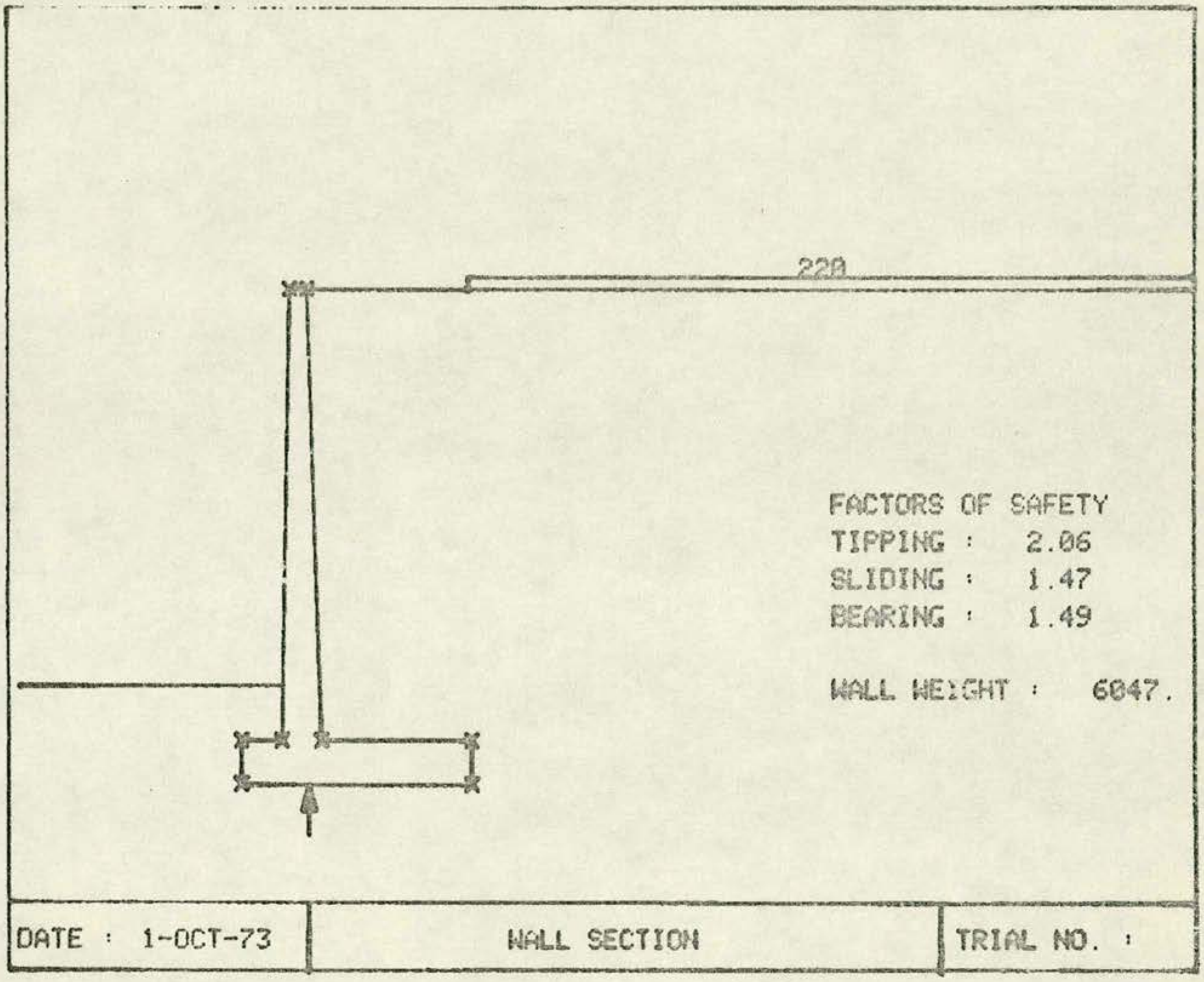
X-COORD	:	6.00
Y-COORD	:	29.00
SLOPE	:	0.00
SURCHARGE	:	0.00

FOUNDATION PROPERTIES

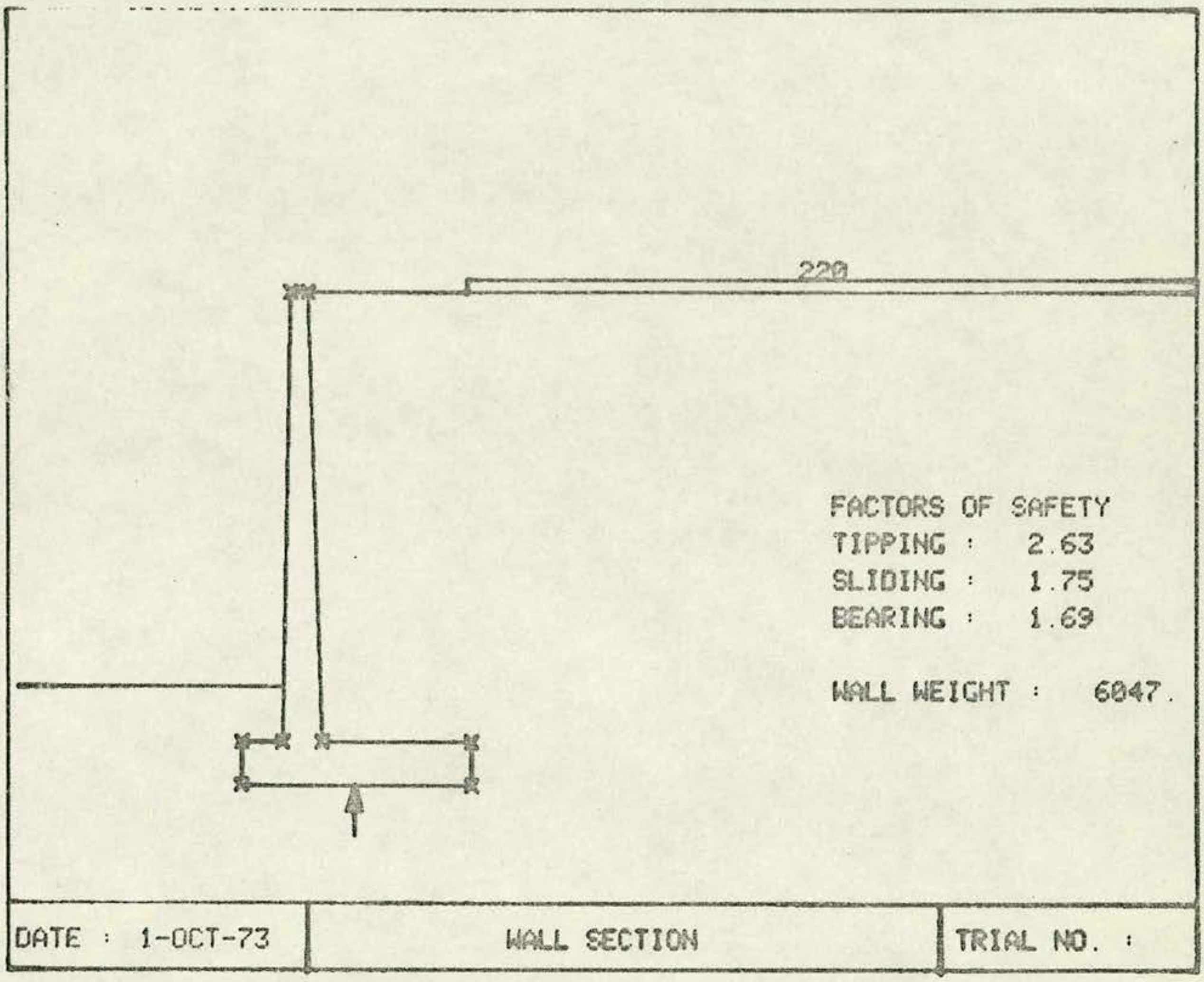
ANGLE OF INTERNAL FRICTION	:	0.50
ANGLE OF WALL FRICTION	:	0.50
BASE ADHESION	:	0.00
BEARING CAPACITY	:	6860.00
BEARING MAXIMUM		0.00

DATE : 1-OCT-73	BASIC DATA	TRIAL NO. :

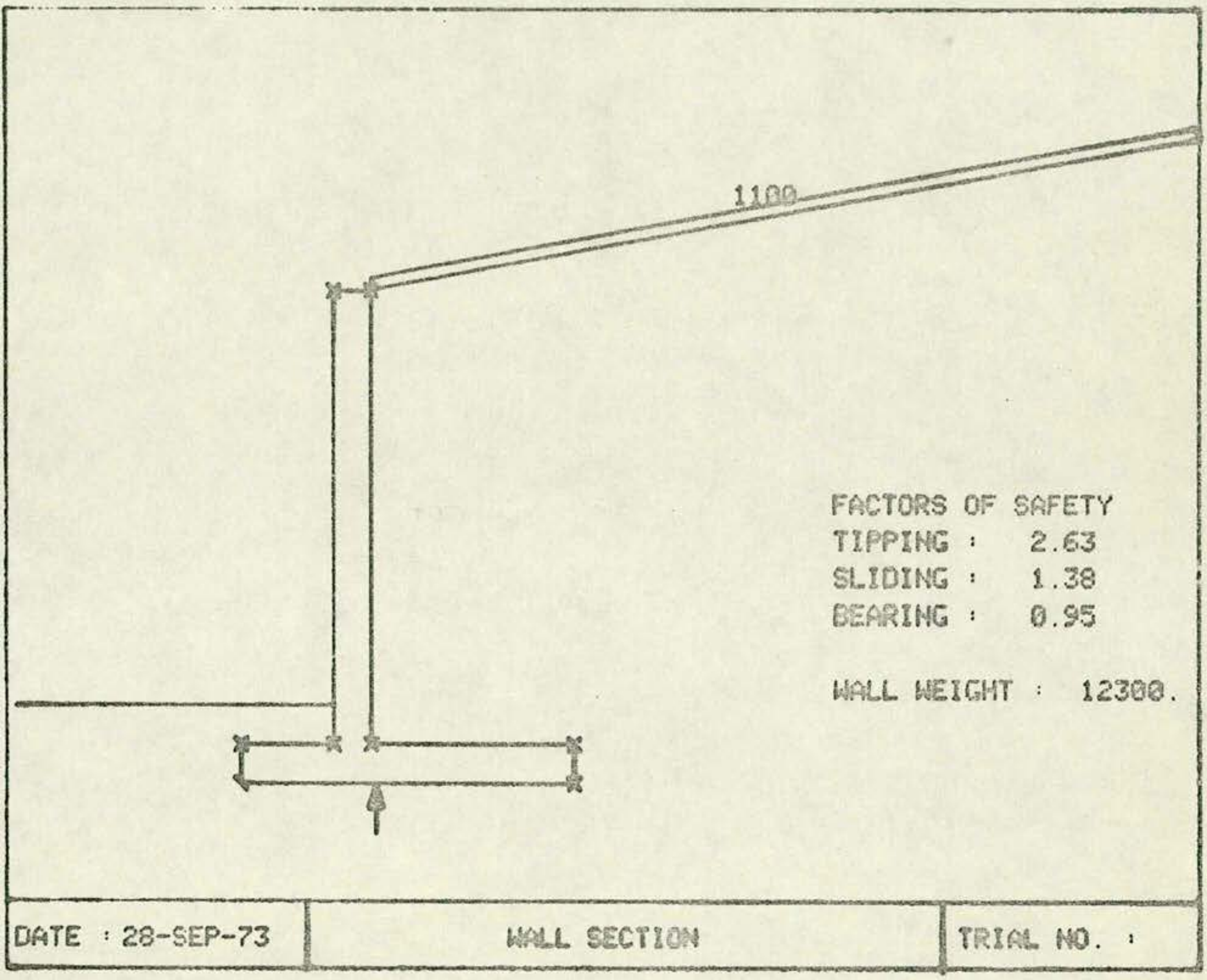
TRIAL C4 : BASIC DATA



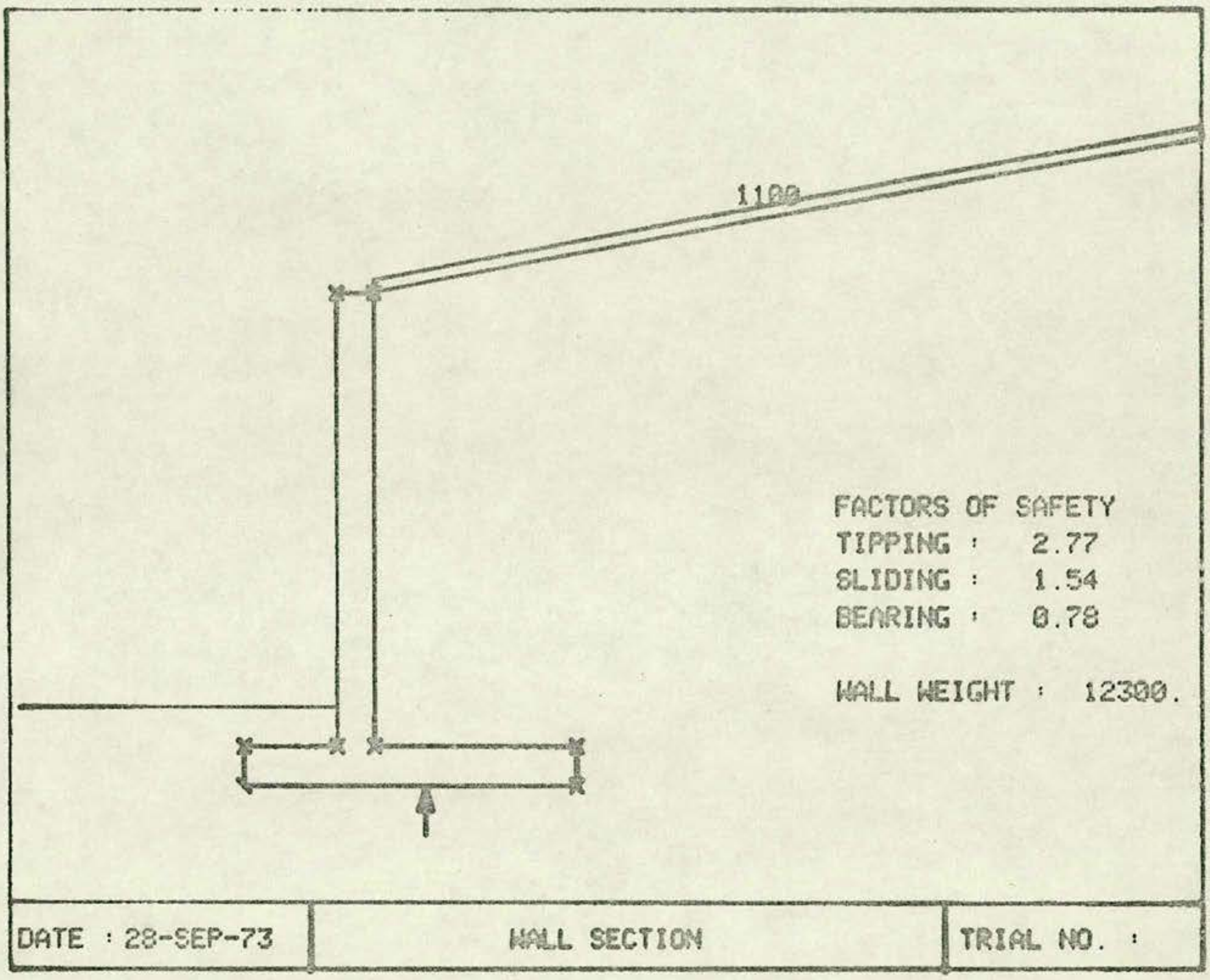
TRIAL C4 : SIMPLE ANALYSIS RESULTS



TRIAL C4 : INCLUDED WEDGE ANALYSIS RESULTS



TRIAL C5 : SIMPLE ANALYSIS RESULTS



TRIAL C5 : INCLUDED WEDGE ANALYSIS RESULTS

WALL COORDINATES

X	Y
40.00	39.50
40.00	40.00
40.50	40.00
40.50	45.00
41.00	45.00
41.00	40.00
43.30	40.00
43.30	39.50

GROUND COORDINATES

X	Y	SURCHARGE
41.00	45.00	6.00
241.00	45.00	

BACKFILL PROPERTIES

ANGLE OF INTERNAL FRICTION	:	0.52
ANGLE OF WALL FRICTION	:	0.34
DRY DENSITY	:	19.20
SATURATED DENSITY	:	21.58
COHESIVE STRENGTH	:	0.00
ADHESIVE STRENGTH	:	0.00

FRONT CONDITIONS

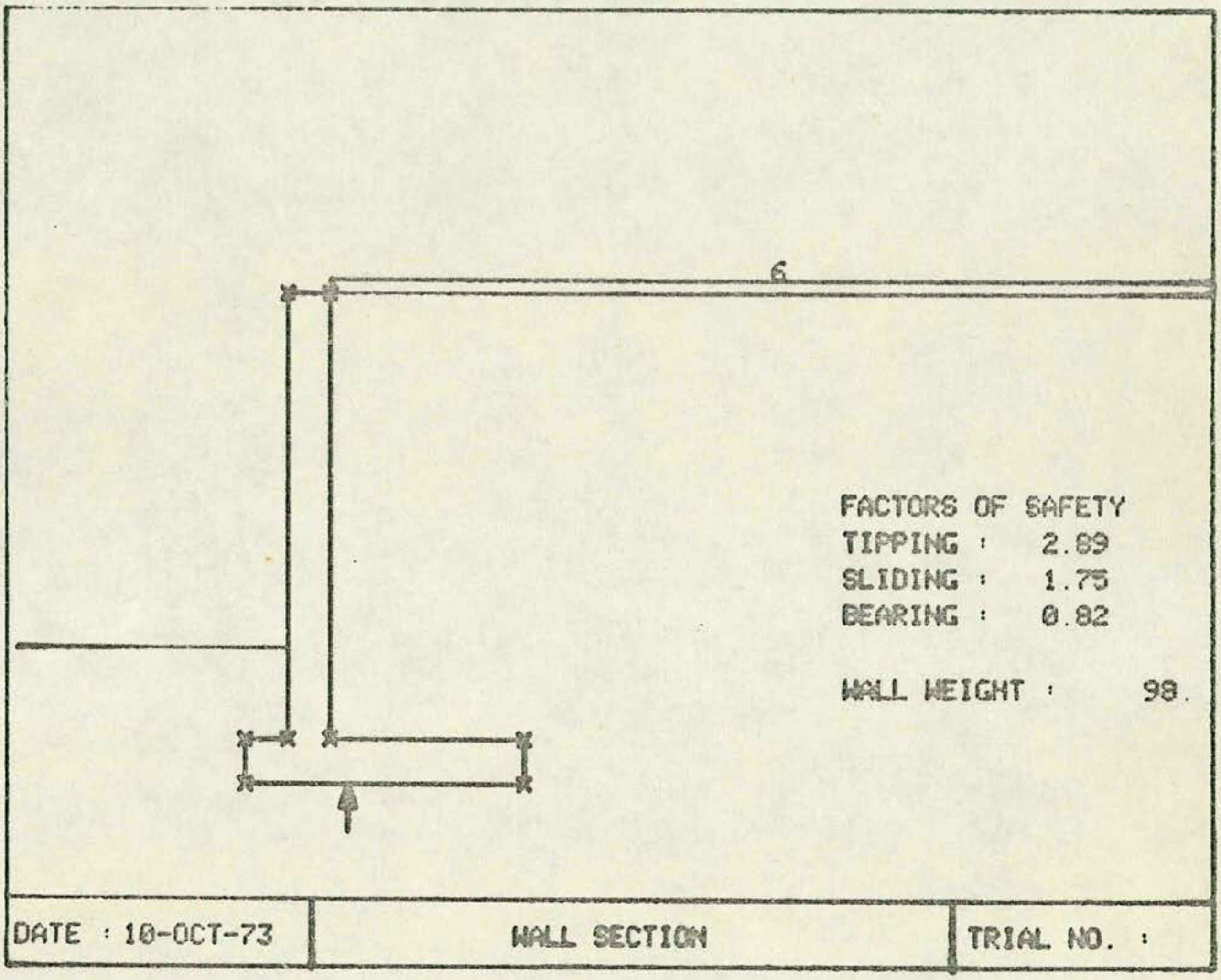
X-COORD	:	6.00
Y-COORD	:	41.00
SLOPE	:	0.00
SURCHARGE	:	0.00

FOUNDATION PROPERTIES

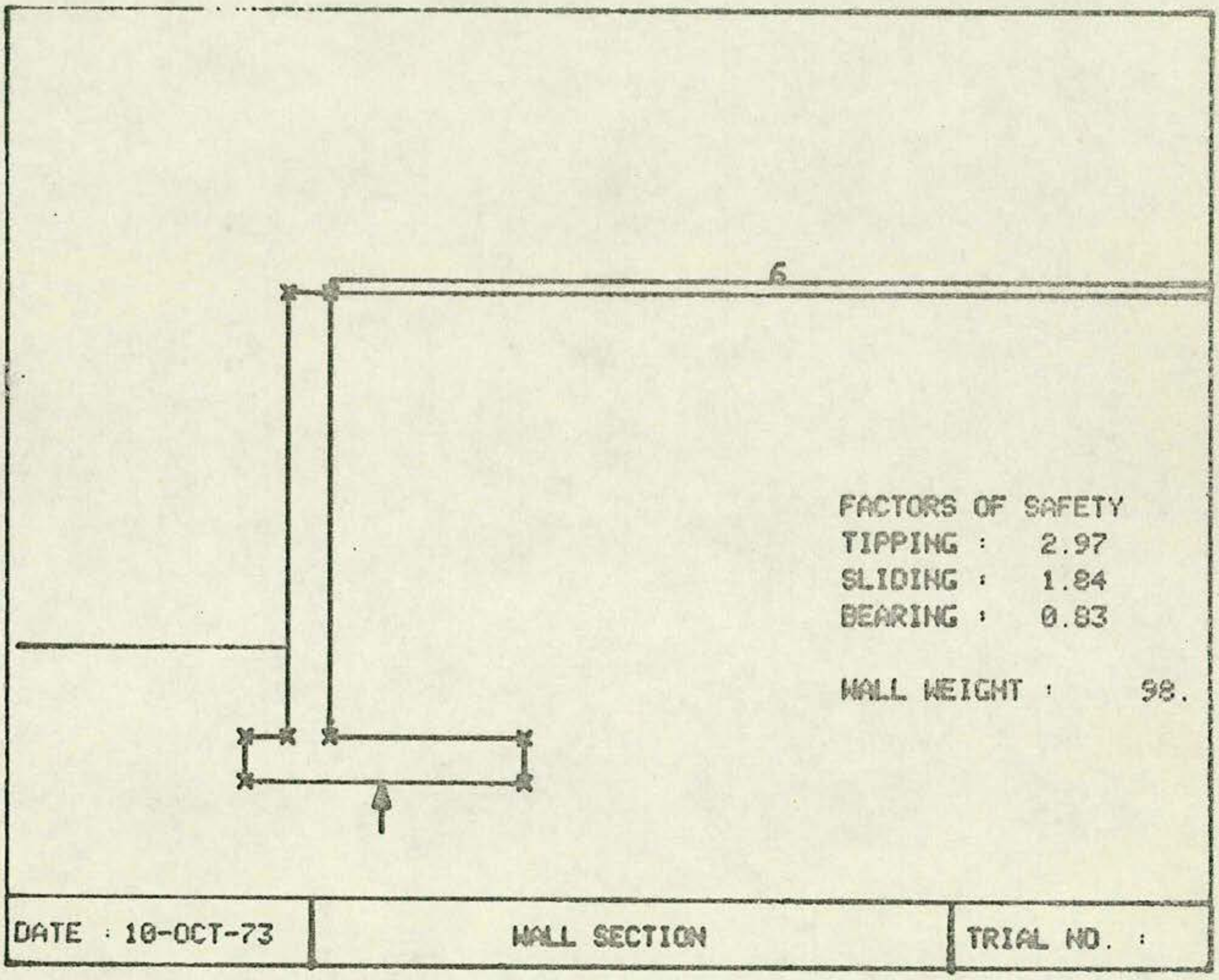
ANGLE OF INTERNAL FRICTION	:	0.52
ANGLE OF WALL FRICTION	:	0.52
BASE ADHESION	:	0.00
BEARING CAPACITY	:	110.00
BEARING MAXIMUM		0.00

DATE : 3-OCT-73	BASIC DATA	TRIAL NO. :

TRIAL C6 : BASIC DATA



TRIAL C6 : SIMPLE ANALYSIS RESULTS



TRIAL C6 : INCLUDED WEDGE ANALYSIS RESULTS

WALL COORDINATES

X	Y
34.00	20.00
34.00	22.00
39.00	22.00
40.00	45.00
41.00	45.00
41.00	22.00
49.00	22.00
49.00	20.00

GROUND COORDINATES

X	Y	SURCHARGE
41.00	45.00	0.00
58.00	55.00	0.00
62.00	55.00	1000.00
76.00	55.00	0.00
269.00	55.00	

BACKFILL PROPERTIES

ANGLE OF INTERNAL FRICTION	:	0.52
ANGLE OF WALL FRICTION	:	0.34
DRY DENSITY	:	110.00
SATURATED DENSITY	:	110.00
COHESIVE STRENGTH	:	0.00
ADHESIVE STRENGTH	:	0.00

FRONT CONDITIONS

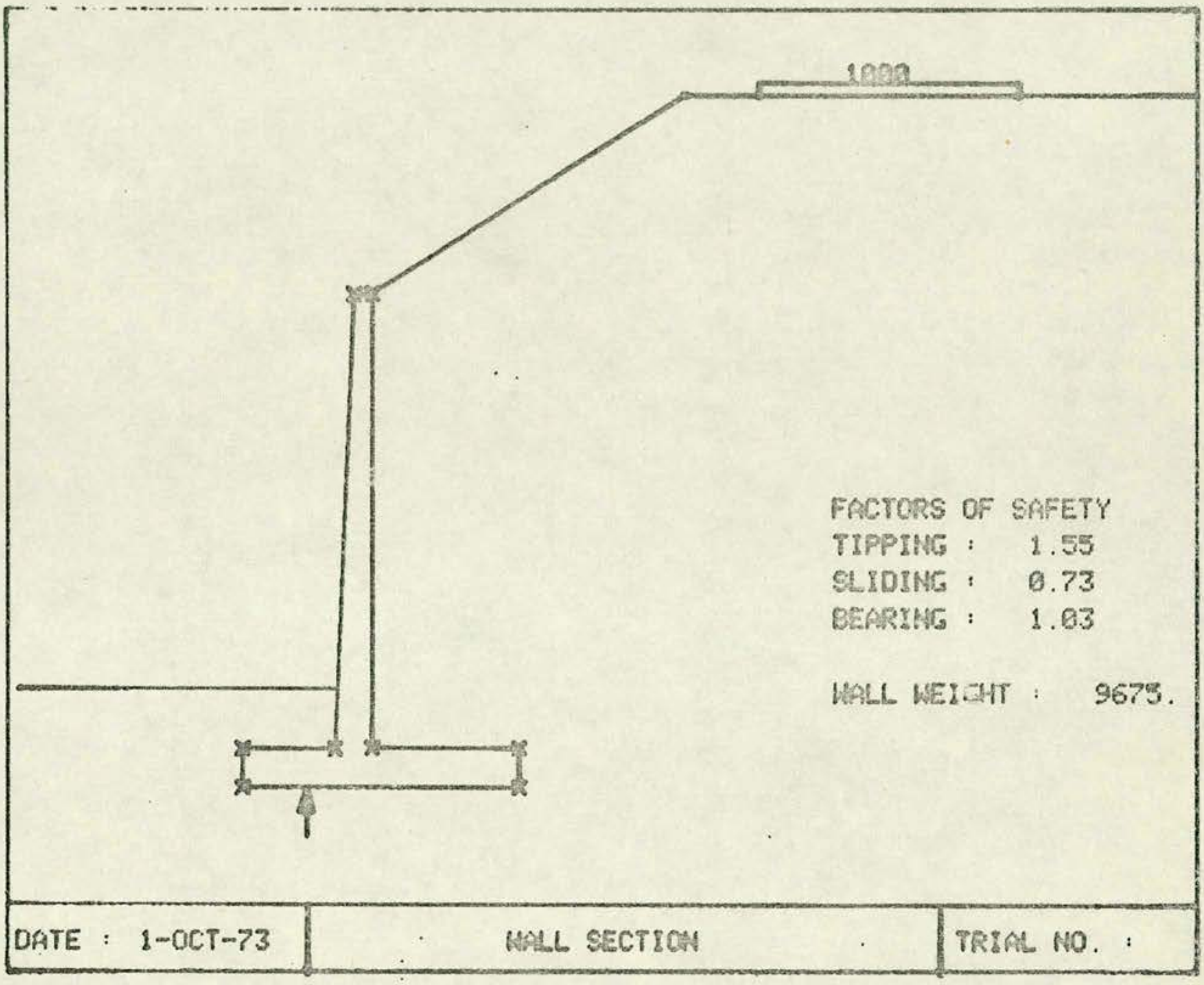
X-COORD	:	6.00
Y-COORD	:	25.00
SLOPE	:	0.00
SURCHARGE	:	0.00

FOUNDATION PROPERTIES

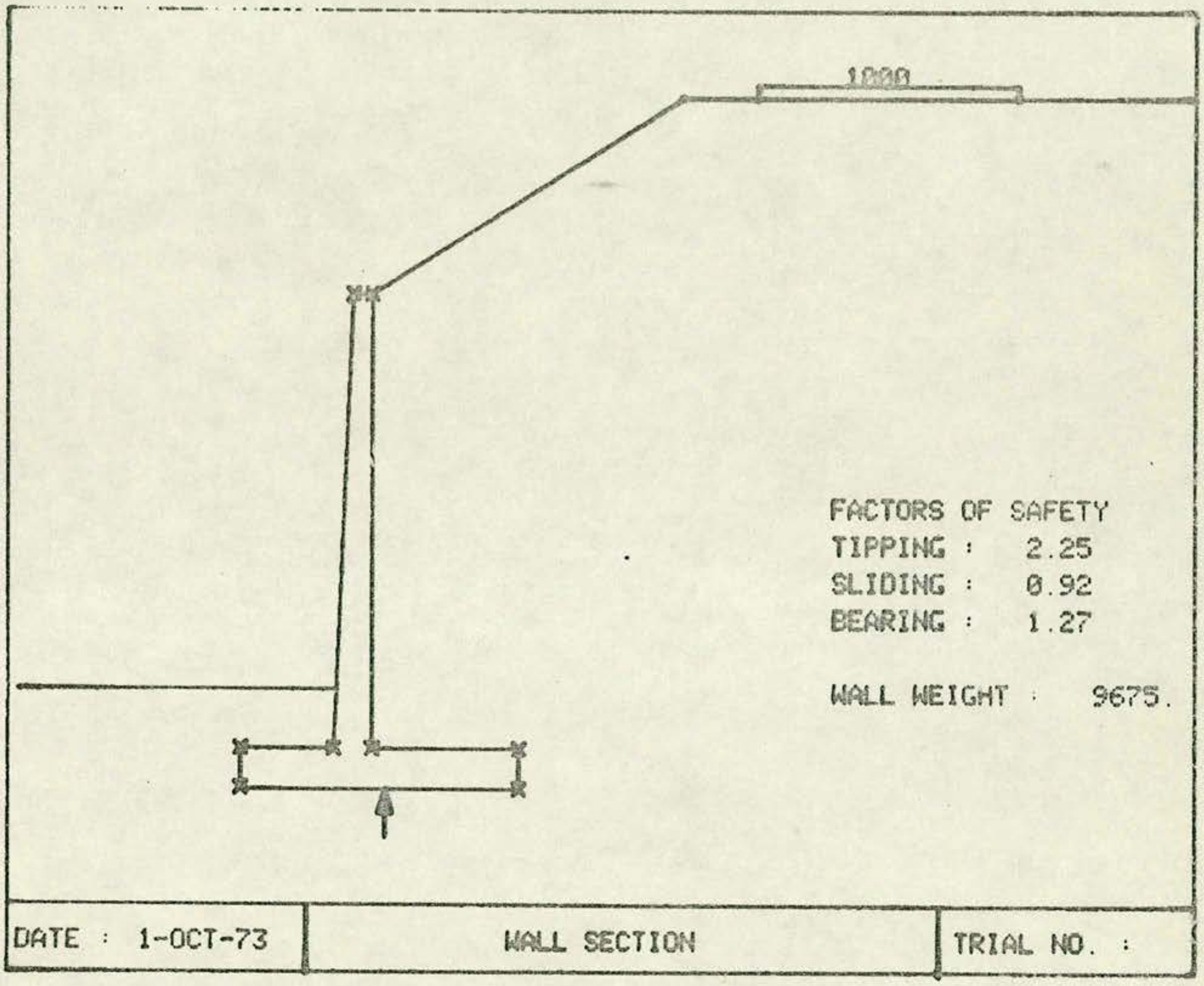
ANGLE OF INTERNAL FRICTION	:	0.34
ANGLE OF WALL FRICTION	:	0.34
BASE ADHESION	:	0.00
BEARING CAPACITY	:	6860.00
BEARING MAXIMUM		0.00

DATE : 1-OCT-73	BASIC DATA	TRIAL NO. :

TRIAL C7 : BASIC DATA



TRIAL C7 : SIMPLE ANALYSIS RESULTS



TRIAL C7 : INCLUDED WEDGE ANALYSIS RESULTS

WALL COORDINATES

X	Y
35.00	25.00
35.00	27.00
38.00	27.00
39.00	45.00
41.00	45.00
41.00	27.00
50.00	27.00
50.00	25.00

GROUND COORDINATES

X	Y	SURCHARGE
41.00	45.00	0.00
46.00	48.00	0.00
57.00	48.00	0.00
67.00	54.00	0.00
267.00	54.00	

BACKFILL PROPERTIES

ANGLE OF INTERNAL FRICTION	:	0.52
ANGLE OF WALL FRICTION	:	0.35
DRY DENSITY	:	110.00
SATURATED DENSITY	:	110.00
COHESIVE STRENGTH	:	0.00
ADHESIVE STRENGTH	:	0.00

FRONT CONDITIONS

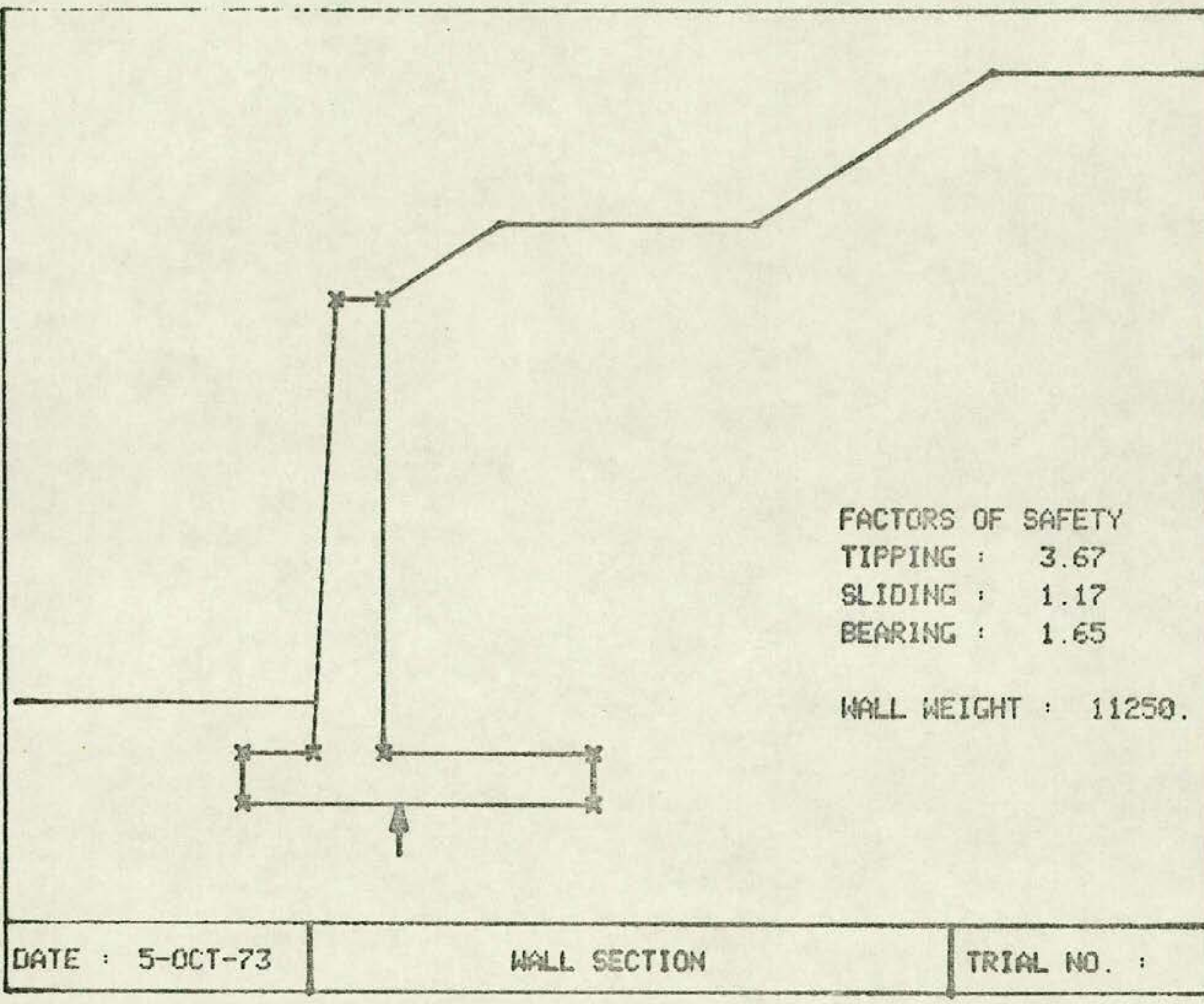
X-COORD	:	6.00
Y-COORD	:	29.00
SLOPE	:	0.00
SURCHARGE	:	0.00

FOUNDATION PROPERTIES

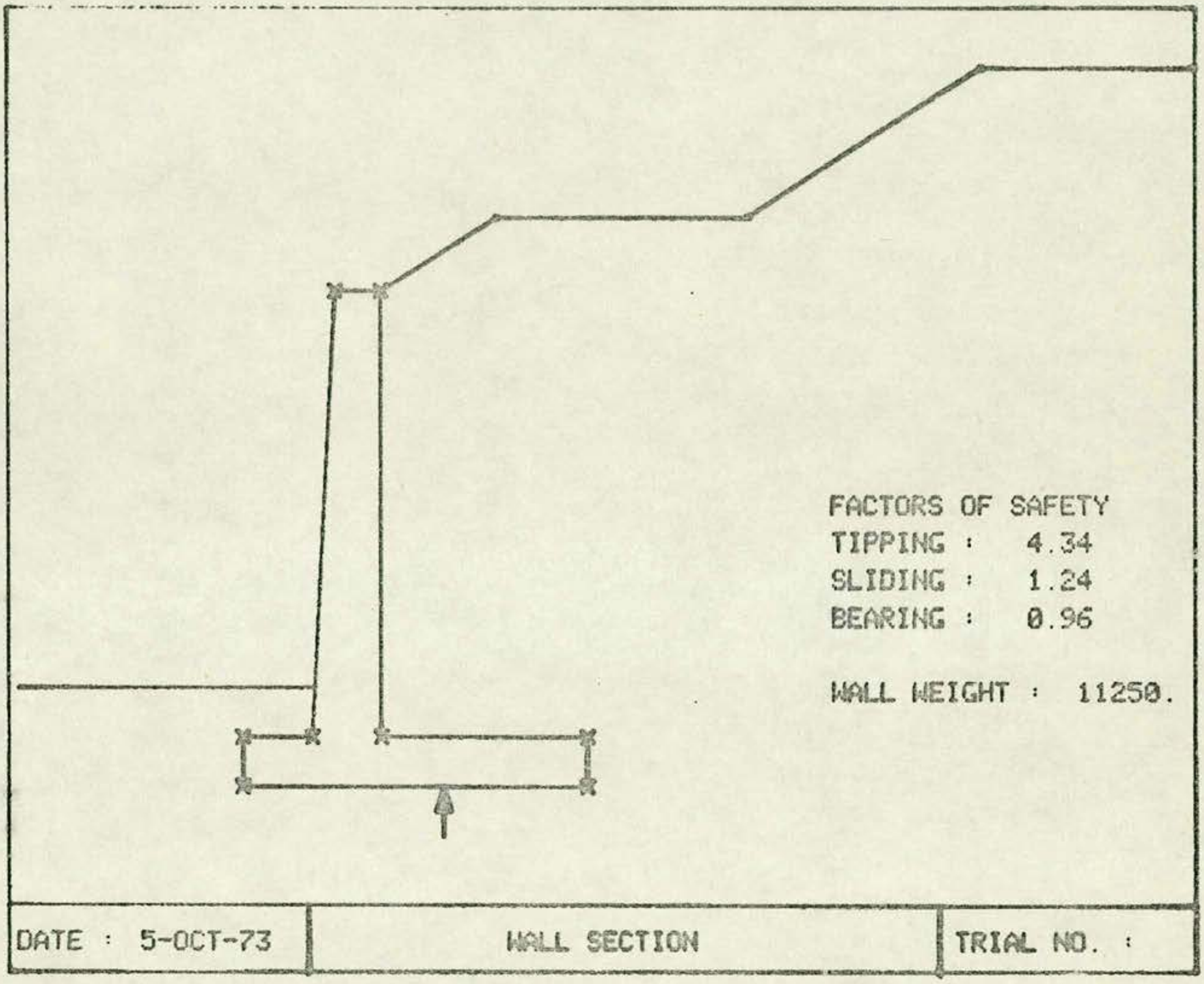
ANGLE OF INTERNAL FRICTION	:	0.52
ANGLE OF WALL FRICTION	:	0.35
BASE ADHESION	:	0.00
BEARING CAPACITY	:	5000.00
BEARING MAXIMUM		0.00

DATE : 5-OCT-73	BASIC DATA	TRIAL NO. :

TRIAL C8 : BASIC DATA



TRIAL C8 : SIMPLE ANALYSIS RESULTS



TRIAL C8 : INCLUDED WEDGE ANALYSIS RESULTS

WALL COORDINATES

X	Y
29.00	5.00
29.00	7.00
39.00	7.00
40.00	45.00
41.00	45.00
41.00	7.00
54.00	7.00
54.00	5.00

GROUND COORDINATES

X	Y	SURCHARGE
41.00	45.00	0.00
241.00	99.00	

BACKFILL PROPERTIES

ANGLE OF INTERNAL FRICTION :	0.17
ANGLE OF WALL FRICTION :	0.10
DRY DENSITY :	100.00
SATURATED DENSITY :	100.00
COHESIVE STRENGTH :	600.00
ADHESIVE STRENGTH :	400.00

FRONT CONDITIONS

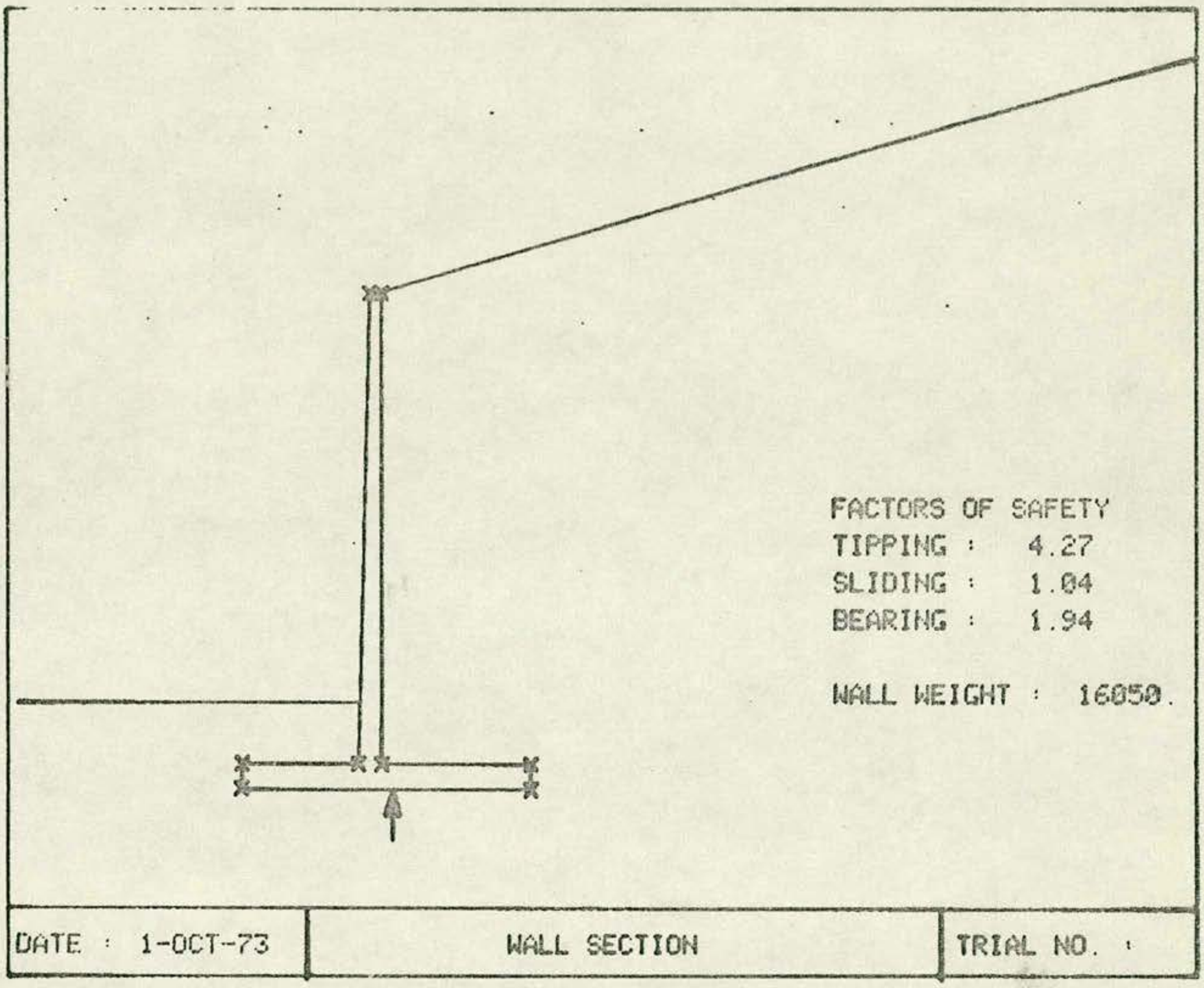
X-COORD :	6.00
Y-COORD :	12.00
SLOPE :	0.00
SURCHARGE :	0.00

FOUNDATION PROPERTIES

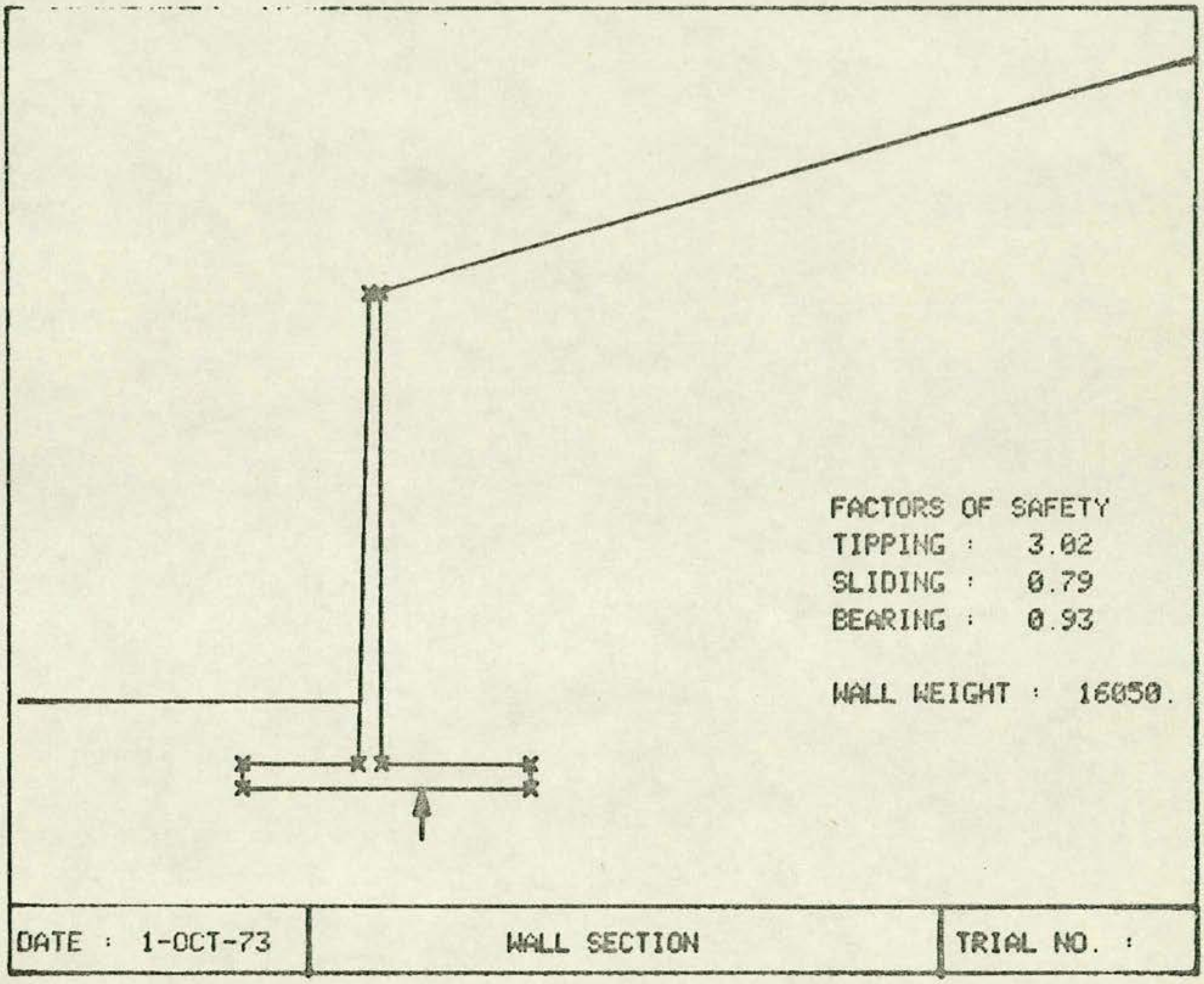
ANGLE OF INTERNAL FRICTION :	0.10
ANGLE OF WALL FRICTION :	0.10
BASE ADHESION :	600.00
BEARING CAPACITY :	6860.00
BEARING MAXIMUM	0.00

DATE : 1-OCT-73	BASIC DATA	TRIAL NO. :

TRIAL C9 : BASIC DATA



TRIAL C9 : SIMPLE ANALYSIS RESULTS



TRIAL C9 : INCLUDED WEDGE ANALYSIS RESULTS

WALL COORDINATES

X	Y
40.00	39.50
40.00	40.00
40.50	40.00
40.50	45.00
41.00	45.00
41.00	40.00
42.75	40.00
42.75	39.50

GROUND COORDINATES

X	Y	SURCHARGE
41.00	45.00	24.00
241.00	45.00	

BACKFILL PROPERTIES

ANGLE OF INTERNAL FRICTION :	0.00
ANGLE OF WALL FRICTION :	0.00
DRY DENSITY :	20.60
SATURATED DENSITY :	20.60
COHESIVE STRENGTH :	21.00
ADHESIVE STRENGTH :	14.00

FOUNDATION PROPERTIES

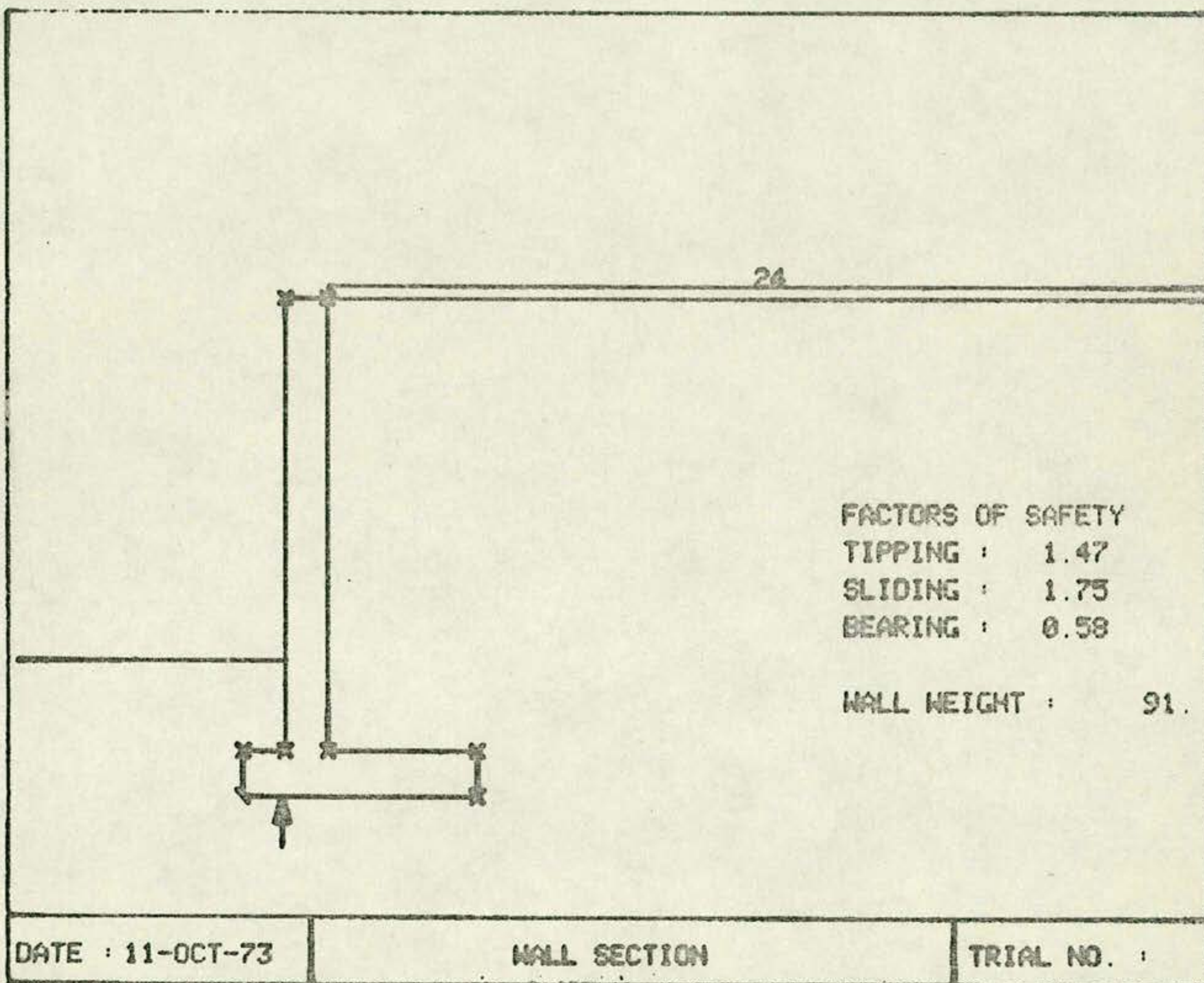
ANGLE OF INTERNAL FRICTION :	0.28
ANGLE OF WALL FRICTION :	0.28
BASE ADHESION :	110.00
BEARING CAPACITY :	270.00
BEARING MAXIMUM	0.00

FRONT CONDITIONS

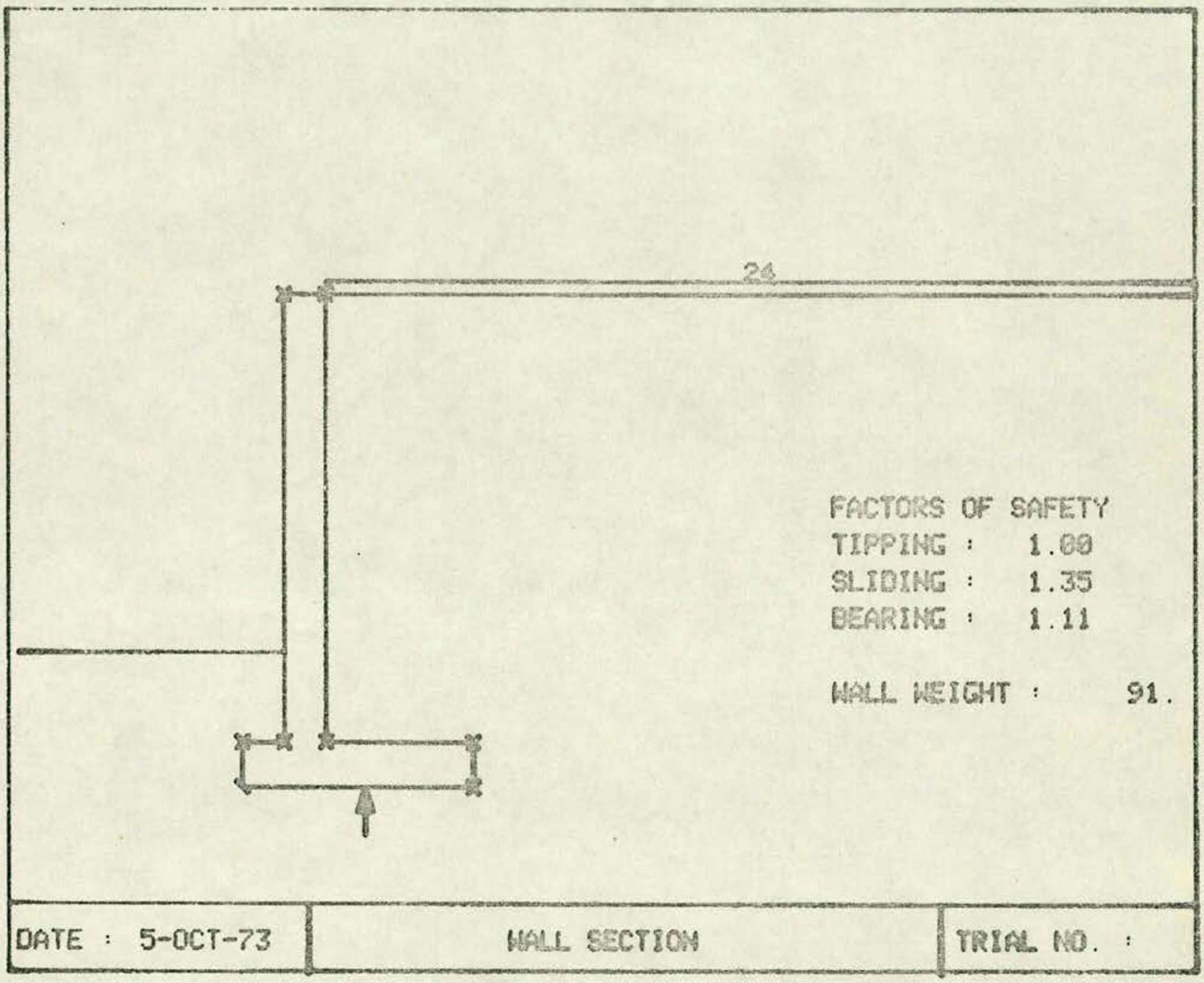
X-COORD :	6.00
Y-COORD :	41.00
SLOPE :	0.00
SURCHARGE :	0.00

DATE : 5-OCT-73	BASIC DATA	TRIAL NO. :

TRIAL C10 : BASIC DATA



TRIAL C10 : SIMPLE ANALYSIS RESULTS



TRIAL C10 : INCLUDED WEDGE ANALYSIS RESULTS

WALL COORDINATES	
X	Y
32.00	15.00
32.00	18.00
38.00	18.00
39.50	45.00
41.00	45.00
41.00	18.00
50.00	18.00
50.00	15.00

GROUND COORDINATES		
X	Y	SURCHARGE
41.00	45.00	0.00
47.50	49.00	0.00
61.00	49.00	0.00
73.00	55.00	0.00
277.00	55.00	

BACKFILL PROPERTIES

ANGLE OF INTERNAL FRICTION	: 0.11
ANGLE OF WALL FRICTION	: 0.07
DRY DENSITY	: 100.00
SATURATED DENSITY	: 100.00
COHESIVE STRENGTH	: 400.00
ADHESIVE STRENGTH	: 260.00

FOUNDATION PROPERTIES

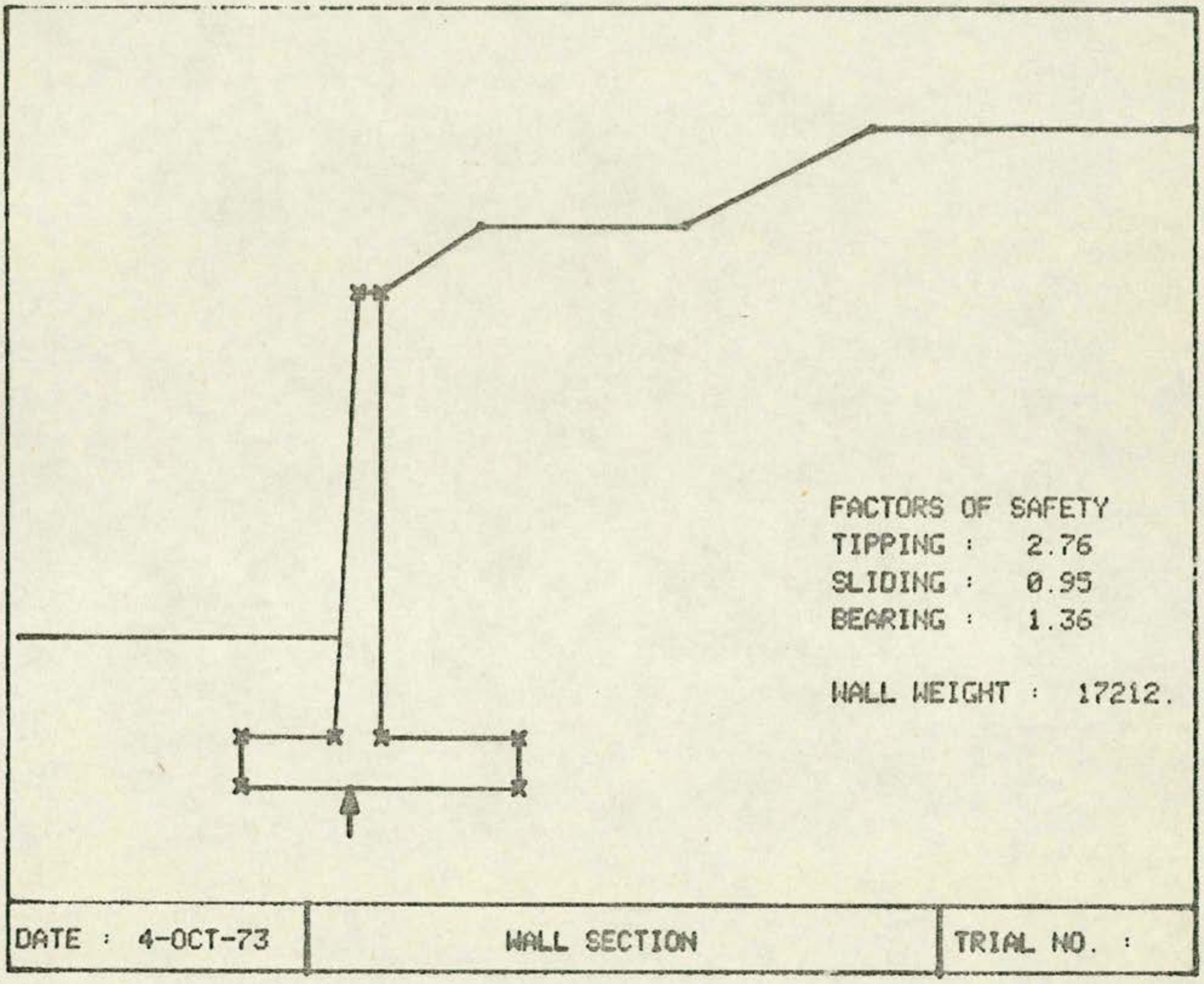
ANGLE OF INTERNAL FRICTION	: 0.11
ANGLE OF WALL FRICTION	: 0.11
BASE ADHESION	: 400.00
BEARING CAPACITY	:6000.00
BEARING MAXIMUM	0.00

FRONT CONDITIONS

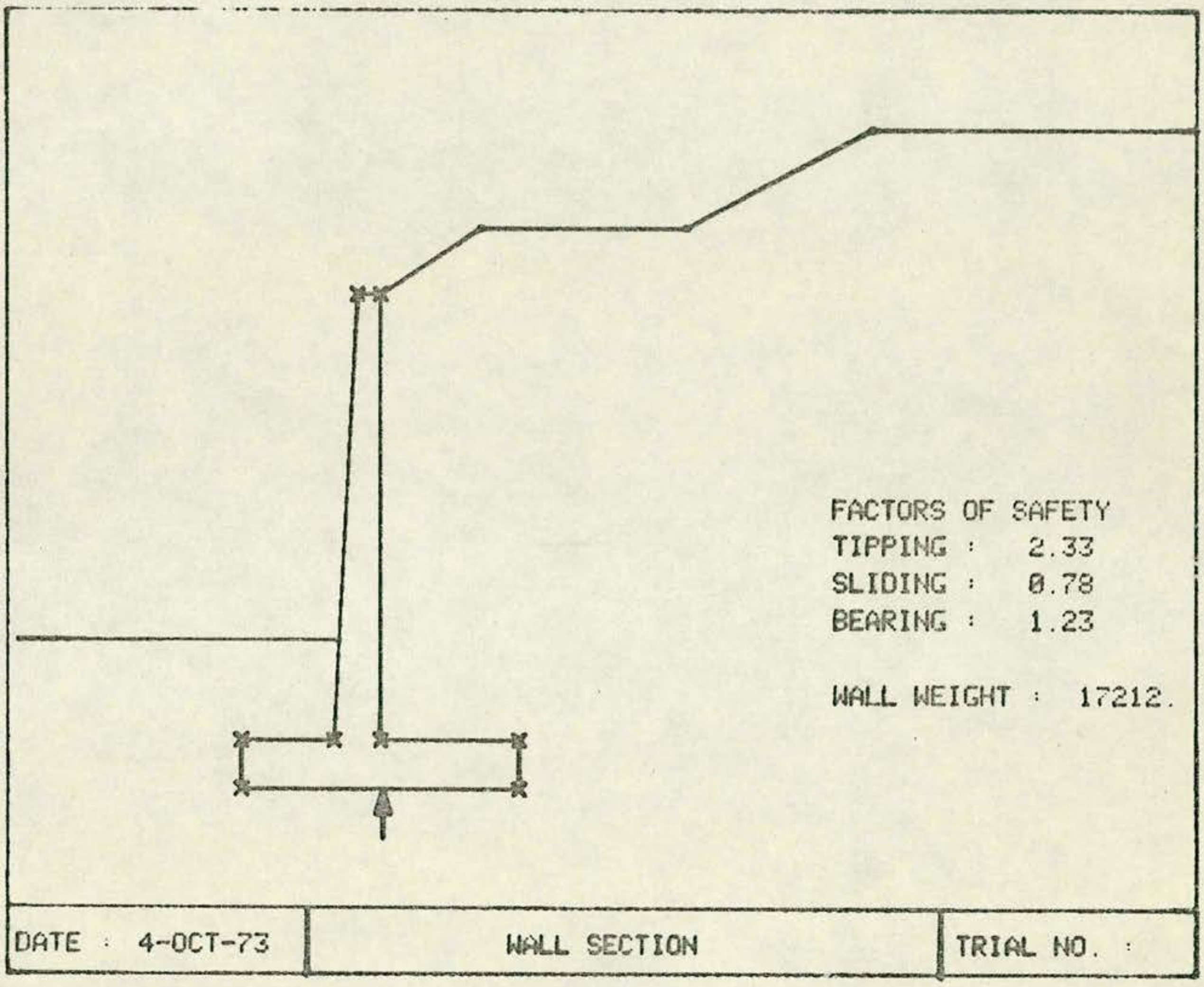
X-COORD	: 6.00
Y-COORD	: 24.00
SLOPE	: 0.00
SURCHARGE	: 0.00

DATE : 4-OCT-73	BASIC DATA	TRIAL NO. :

TRIAL C11 : BASIC DATA



TRIAL C11 : SIMPLE ANALYSIS RESULTS



TRIAL C11 : INCLUDED WEDGE ANALYSIS RESULTS

WALL COORDINATES

X	Y
33.00	15.00
33.00	17.00
39.00	17.00
40.00	45.00
41.00	45.00
41.00	17.00
54.00	17.00
54.00	15.00

GROUND COORDINATES

X	Y	SURCHARGE
41.00	45.00	0.00
63.00	55.00	0.00
68.00	55.00	1000.00
82.00	55.00	0.00
87.00	55.00	0.00
92.00	52.00	0.00
102.00	52.00	0.00
202.00	84.50	

BACKFILL PROPERTIES

ANGLE OF INTERNAL FRICTION	:	0.11
ANGLE OF WALL FRICTION	:	0.07
DRY DENSITY	:	100.00
SATURATED DENSITY	:	100.00
COHESIVE STRENGTH	:	400.00
ADHESIVE STRENGTH	:	260.00

FOUNDATION PROPERTIES

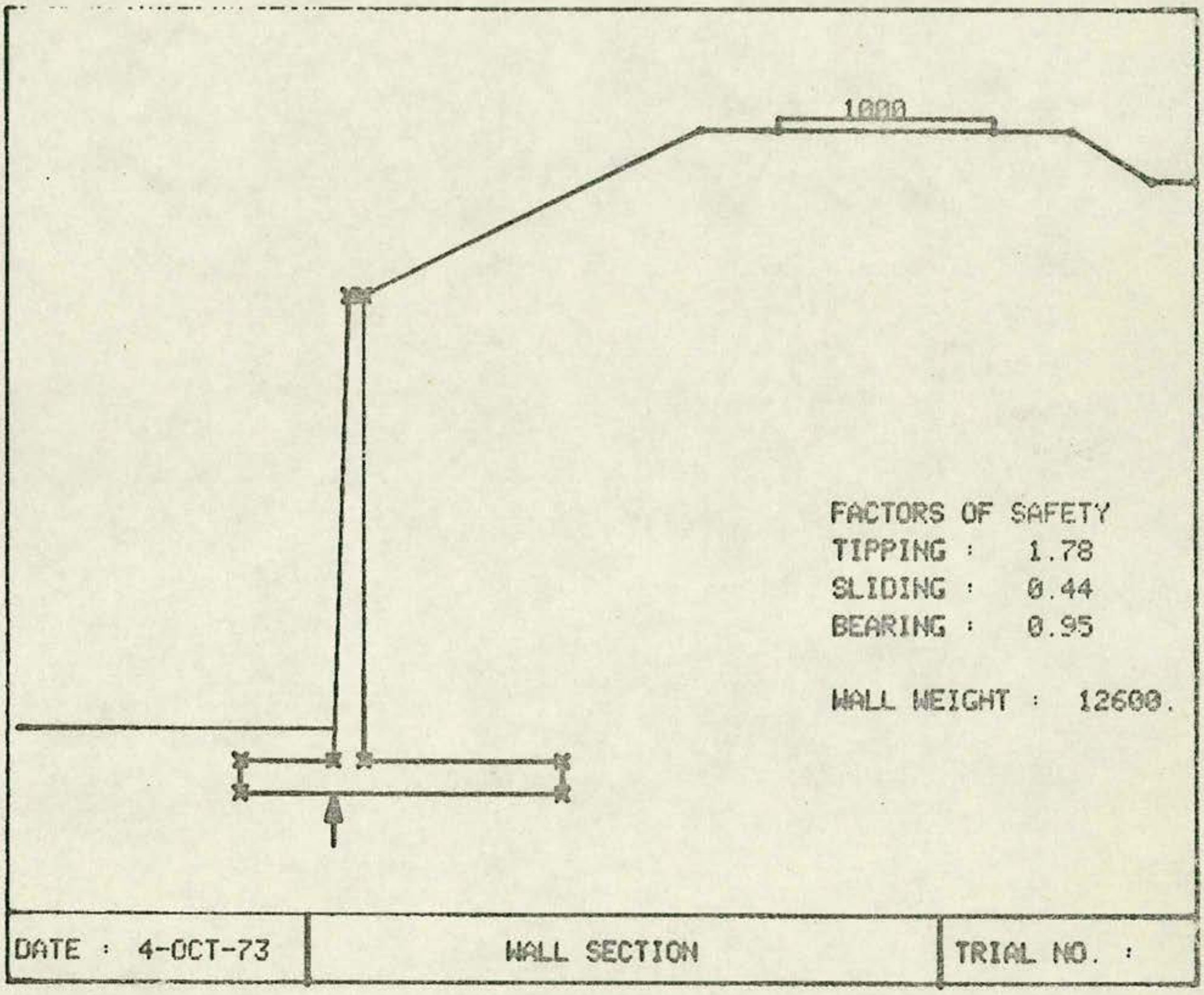
ANGLE OF INTERNAL FRICTION	:	0.11
ANGLE OF WALL FRICTION	:	0.11
BASE ADHESION	:	400.00
BEARING CAPACITY	:	6000.00
BEARING MAXIMUM		0.00

FRONT CONDITIONS

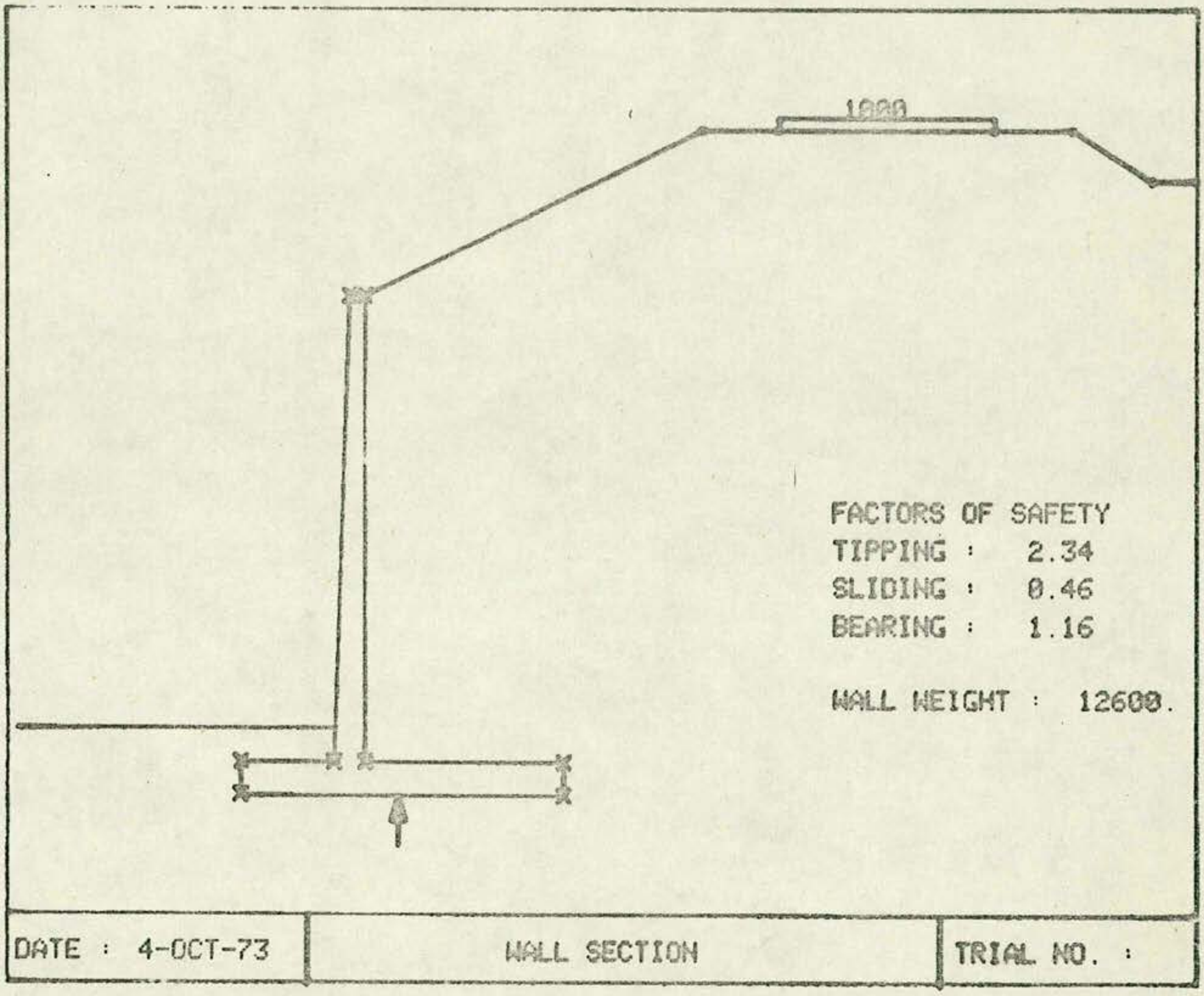
X-COORD	:	6.00
Y-COORD	:	19.00
SLOPE	:	0.00
SURCHARGE	:	0.00

DATE : 4-OCT-73	BASIC DATA	TRIAL NO. :

TRIAL C12 : BASIC DATA



TRIAL C12 : SIMPLE ANALYSIS RESULTS



TRIAL C12 : INCLUDED WEDGE ANALYSIS RESULTS

APPENDIX 111 : PROGRAM LISTING

```
C     *** MAIN PROGRAM ***

      COMMON IDFILE(2000)
      COMMON/BLOCK1/AMMTY,AREA
      COMMON/BLOCK2/SIGNR,ANGR,ALR,XR,YR
      COMMON/BLOCK3/XT,YT,ANGF
      COMMON/BLOCK4/QS,QWS,PYE,PYE2,PYE4
      COMMON/BLOCK5/QFRONT,ANGFRT
      COMMON/BLOCK6/WX,WY,XWLFRT,YWLFRT
      COMMON/BLOCK7/XPASE,YPASE,APASE,PASIVE
      COMMON/BLOCK8/CB,CA
      COMMON/BLOCK9/SAVEPP,SAVPP1,SAVPP2
      COMMON/BLOCKA/MINBAS(10)
      COMMON/BLOCKB/XTOP,YTOP,YBOT,XBOT,NTOP,NBOT
      COMMON/BLOCKC/UP,WATER,PB2,PWATER
      COMMON/BLOCKD/SUMWT,SUMMTY
      COMMON/BLOCKE/PB1
      COMMON/BLOCKF/XISLOP,YISLOP,WSAVEX,WSAVEY,XNC,YNC
      COMMON/BLOCKG/NLIM1,NLIM2,NLIM3,NLIM5
      COMMON/BLOCKH/PATOP,XPATOP,YPATOP,PABOT,XPABOT,YPABOT
      COMMON/BLOCKI/WALLXX,WALLYY,NOBC,NC,ISLOPE
      COMMON/BLOCKK/TOEDEP,RATIO
      COMMON/BLOCKN/ANGTOP,ANGBOT,ANGBAS
      COMMON/BLOCKO/DELBOT,DELTOP,ACTIVE(12),BACK
      COMMON/BLOCKP/PWTOP,XPWTOP,YPWTOP,PWBAS,XPWBAS,YPWBAS
      COMMON/BLOCKQ/H0,XSAVE,YSAVE,SX,SY,WATERB
      COMMON/BLOCKR/IA,TANS,DELTAW,WDASH,SURWT,SURCH,XSUR,YSUR,XWH0
      COMMON/BLOCKS/X,Y
      COMMON/BLOCKV/INO,JNO,TCSURW,PRUNE
      COMMON/BLOCKU/JSTART,JEND,ZH0,ZS,XH0
      COMMON/BLOCKW/RERUN,NSC,XXXIT,MANUAL,CRITTP,CRITSL,CRITBC,WWALL
      COMMON/GROUPD/APATOP,APABOT,PABASE,APABAS,XPABAS,YPABAS
      COMMON/GROUPE/XWT,YWT,XWB,YWB,PW,XPW,YPW,APW
      COMMON/GROUPF/DEPKEY,WIDKEY,XWATB,YWATB
      COMMON/GROUPG/CFOUND,QFS,QWFS,Q0,QNCMAX,XFRONT,YFRONT
      COMMON/GROUPI/RESTP,RESSL,RESBC,RESBAS,RESWAL
      COMMON/GROUPJ/BASETD,TOE1,DELTOE,NTOED,OVMIN,OVMAX,DELTAB
      COMMON/GROUPK/GO,APPLE,NRATIO,RATIOS,BASELO,BASIC(25)
      COMMON/GROUPL/TSTEM,TBASE,HFRONT,DFSTIP,DFSLID,DFSBCY
      COMMON/GROUPM/XBASE,YBASE
      COMMON/GROUPN/PWBOT,XPWBOT,YPWBOT,APWTOP,APWBOT,APWBAS



      DIMENSION WX(12),WY(12),SX(12),SY(12),WXSAVE(12),WYSAVE(12)
      DIMENSION BASELO(10),XTOP(15),YTOP(15),YBOT(15),XBOT(15)
      DIMENSION RESBAS(30),RATIOS(10),SURCH(12),XSTART(7),XEND(7)
      DIMENSION WALLXX(4)
      DIMENSION RESTD(30),WALLYY(4),XDASH1(12),YDASH1(12),YDASH2(12)
      DIMENSION RESTP(30),RESSL(30),RESBC(30),IRESNA(30),RESRAT(30)
      DIMENSION RESWAL(30),BASETD(10),STOE(11),SRATIO(11),SSBASE(11)


      LOGICAL STORE,RERUN,THIRD,CRACK,XXXIT,MANUAL,SIMPLE,PRUNE
      LOGICAL SIMON,GO,MANDAT


C     **** SET INITIAL VALUES ****
```

```
C       SET LOGICAL VARIABLES TO INITIAL VALUES
        LOG=.TRUE.
        STORE=.FALSE.
        LOGF=.FALSE.
        GO=.FALSE.
        MANDAT=.FALSE.


C       SET CONSTANT TERMS
        NLIM1=3
        NLIM2=6
        NLIM3=NLIM2+1
        NLIM5=NLIM1+1
        ANLIM=NLIM1
        WEDGNO=6.00
        NOWEDG=WEDGNO-1
        PYE=3.142
        PYE2=1.571
        PYE4=0.785
        PYE18=0.1745
        PYE180=0.01745


        CALL DEFPIC(IDFILE,2000)


C       **** DATA INPUT ****

C       SELECT METHOD FOR DATA INPUT
   40   CALL ERASE
        RERUN=.FALSE.
        CALL SENDHS('DATA INPUT WILL BE :- ')
        CALL SENDHS('.')
        CALL SENDHS('MANUAL')
        CALL SENDHS('VIA DATA FILE')
        CALL MENUIN(LOGF,1)
        CALL INSERT('        1',3)
        CALL INSERT('        2',3)
        CALL CURSOR(JC,ICX,ICY)
        KEY=IPOSN(ICY)
        IF(KEY.GT.1)GO TO 60


C       MANUAL INPUT OF DATA
        CALL ERASE
        CALL SENDHS('**WALL COORDINATES**')
        CALL SENDHS('HOW MANY COORDINATES :')
        CALL KILLLF
        CALL SENDIN(NC,0,.TRUE.)
        CALL ERASE
        CALL SENDHS('     WALL COORDINATES')
        CALL MOVETO(215,760,IDUM,0,1)
        CALL LINE(227,0,.TRUE.)
        CALL SENDHS('.')
```

```
      CALL SENDHS('   WX(I)          WY(I)')
      CALL MOVETO(204,718,IDUM,0,1)
      CALL LINE(70,0,.TRUE.)
      CALL LINE(102,0,.FALSE.)
      CALL LINE(75,0,.TRUE.)
      CALL DEPICT(IDFILE,1)
      DO 42 I=1,NC
      CALL NOECHO
      CALL SENDRL(WX(I),0,0,.TRUE.)
      CALL ECHO
      IY=700-40*I
      CALL MOVETO(200,IY,IDUM,0,1)
      CALL RLDISP(WX(I),6,2)
      CALL DEPICT(IDFILE,1)
      CALL NOECHO
      CALL SENDRL(WY(I),0,0,.TRUE.)
      CALL ECHO
      CALL MOVETO(370,IY,IDUM,0,1)
      CALL RLDISP(WY(I),6,2)
      CALL DEPICT(IDFILE,1)
   42 CONTINUE
      PAUSE


      CALL ERASE
      CALL SENDHS('**BACKFILL COORDINATES**')
      CALL SENDHS('HOW MANY COORDINATES :')
      CALL KILLLF
      CALL SENDIN(NSC,0,.TRUE.)
      CALL ERASE
      CALL SENDHS('     BACKFILL COORDINATES')
      CALL MOVETO(215,760,IDUM,0,1)
      CALL LINE(250,0,.TRUE.)
      CALL SENDHS('.')
      CALL SENDHS('   SX(I)          SY(I)')
      CALL MOVETO(204,718,IDUM,0,1)
      CALL LINE(70,0,.TRUE.)
      CALL LINE(102,0,.FALSE.)
      CALL LINE(75,0,.TRUE.)
      CALL DEPICT(IDFILE,1)
      DO 43 I=1,NSC
      CALL NOECHO
      CALL SENDRL(SX(I),0,0,.TRUE.)
      CALL ECHO
      IY=700-40*I
      CALL MOVETO(200,IY,IDUM,0,1)
      CALL RLDISP(SX(I),6,2)
      CALL DEPICT(IDFILE,1)
      CALL NOECHO
      CALL SENDRL(SY(I),0,0,.TRUE.)
      CALL ECHO
      CALL MOVETO(370,IY,IDUM,0,1)
      CALL RLDISP(SY(I),6,2)
      CALL DEPICT(IDFILE,1)
   43 CONTINUE
      PAUSE


      CALL ERASE
      CALL SENDHS('**SURCHARGES**')
```

```
      CALL SENDHS('     SURCH()')
      NSC1=NSC-1
      DO 44 I=1,NSC1
      CALL SENDIN(I,2,.FALSE.)
      CALL KILLLF
   44 CALL SENDRL(SURCH(I),0,0,.TRUE.)


      CALL ERASE
      CALL SENDHS('**BACKFILL PROPERTIES**')
      CALL SENDHS('DRY DENSITY OF SOIL                   :')
      CALL KILLLF
      CALL SENDRL(PB1,0,0,.TRUE.)
      CALL SENDHS('SUBMERGED DENSITY OF SOIL             :')
      CALL KILLLF
      CALL SENDRL(PB2,0,0,.TRUE.)
      CALL SENDHS('ANGLE OF SOIL FRICTION                :')
      CALL KILLLF
      CALL SENDRL(QS,0,0,.TRUE.)
      CALL SENDHS('ANGLE OF WALL FRICTION                :')
      CALL KILLLF
      CALL SENDRL(QWS,0,0,.TRUE.)
      CALL SENDHS('COHESIVE STRENGTH                     :')
      CALL KILLLF
      CALL SENDRL(CB,0,0,.TRUE.)
      CALL SENDHS('ADHESION BETWEEN SOIL AND WALL  :')
      CALL KILLLF
      CALL SENDRL(CA,0,0,.TRUE.)


      CALL SENDHS('.')
      CALL SENDHS('.')
      CALL SENDHS('**FOUNDATION PROPERTIES**')
      CALL SENDHS('ANGLE OF SOIL FRICTION                :')
      CALL KILLLF
      CALL SENDRL(QFS,0,0,.TRUE.)
      CALL SENDHS('ANGLE OF BASE FRICTION                :')
      CALL KILLLF
      CALL SENDRL(QWFS,0,0,.TRUE.)
      CALL SENDHS('SOIL:BASE ADHESION                    :')
      CALL KILLLF
      CALL SENDRL(CFOUND,0,0,.TRUE.)
      CALL SENDHS('BEARING CAPACITY                      :')
      CALL KILLLF
      CALL SENDRL(Q0,0,0,.TRUE.)
      CALL SENDHS('MAXIMUM PERMISSIBLE BC                :')
      CALL KILLLF
      CALL SENDRL(QNCMAX,0,0,.TRUE.)


      CALL SENDHS('.')
      CALL SENDHS('.')
      CALL SENDHS('**FRONT CONDITIONS**')
      CALL SENDHS('XFRONT           :')
      CALL KILLLF
      CALL SENDRL(XFRONT,0,0,.TRUE.)
      CALL SENDHS('YFRONT           :')
      CALL KILLLF
      CALL SENDRL(YFRONT,0,0,.TRUE.)
      CALL SENDHS('ANGFRT           :')
```

```
      CALL KILLLF
      CALL SENDRL(ANGFRT,0,0,.TRUE.)
      CALL SENDHS('SURCHARGE        :')
      CALL KILLLF
      CALL SENDRL(QFRONT,0,0,.TRUE.)

C     INPUT DATA FOR AUTOMATIC ANALYSIS
      CALL SENDHS('.')
      CALL SENDHS('.')
      CALL SENDHS('**DATA REQUIRED FOR AUTOMATIC ANALYSIS**')
      CALL SENDHS('STEM THICKNESS          :')
      CALL KILLLF
      CALL SENDRL(TSTEM,0,0,.TRUE.)
      CALL SENDHS('BASE THICKNESS          :')
      CALL KILLLF
      CALL SENDRL(TBASE,0,0,.TRUE.)
      CALL SENDHS('DESIGN FSTIP            :')
      CALL KILLLF
      CALL SENDRL(DFSTIP,0,0,.TRUE.)
      CALL SENDHS('DESIGN FSLID            :')
      CALL KILLLF
      CALL SENDRL(DFSLID,0,0,.TRUE.)
      CALL SENDHS('DESIGN FSBCY            :')
      CALL KILLLF
      CALL SENDRL(DFSBCY,0,0,.TRUE.)
      MANDAT=.TRUE.
      GO TO 91


C     DATA INPUT VIA DATA FILE
   60 CALL SENDHS('NAME OF DATA FILE :-')
      CALL KILLLF
      CALL READCS(ID,5,IDUM)
      CALL IFILE(1,ID)
C     READ IN WALL COORDINATES
      READ(1,100) NC
      DO 80 I=1,NC
   80 READ(1,110) WX(I),WY(I)


C     READ IN COORDINATES DEFINING BACKFILL PROFILE
      READ(1,100) NSC
      DO 90 I=1,NSC
   90 READ(1,110) SX(I),SY(I)


C     READ IN BACKFILL PROPERTIES
      READ(1,110) PB1,PB2
      READ(1,110) QS,QWS
      READ(1,110) CB,CA


C     READ IN FOUNDATION PROPERTIES
      READ(1,110) QFS,QWFS
      READ(1,110) Q0,QNCMAX
      READ(1,115) CFOUND
```

```
C     READ IN FRONT OF WALL CONDITIONS
      READ(1,110) XFRONT,YFRONT
      READ(1,110) ANGFRT,QFRONT

C     READ IN GROUND WATER CONDITIONS
      READ(1,115) WATERB

C     READ IN TERMS FOR AUTOMATIC ANALYSIS
      READ(1,110) TBASE,TSTEM
      READ(1,120) DFSTIP,DFSLID,DFSBCY
      READ(1,115) HFRONT

C     READ IN SURCHARGE TERMS
      NSC1=NSC-1
      DO 95 I=1,NSC1
   95 READ(1,116) SURCH(I)

C     READ IN WALL DENSITY
      READ(1,115) WALDEN

C     FORMAT STATEMENTS FOR READ IN
  100 FORMAT(I2)
  110 FORMAT(2F8.3)
  115 FORMAT(F8.3)
  116 FORMAT(F9.3)
  120 FORMAT(3F8.2)

C     FORM BASIC DATA ARRAY
   91 BASIC(1)=PB1
      BASIC(2)=PB2
      BASIC(3)=QS
      BASIC(4)=QWS
      BASIC(5)=CB
      BASIC(6)=CA
      BASIC(7)=WATERB
      BASIC(8)=Q0
      BASIC(9)=QNCMAX
      BASIC(10)=QFS
      BASIC(11)=QWFS
      BASIC(12)=CFOUND
      BASIC(13)=TSTEM
      BASIC(14)=TBASE
      BASIC(15)=HFRONT
      BASIC(16)=DFSTIP
      BASIC(17)=DFSLID
      BASIC(18)=DFSBCY
      BASIC(19)=XFRONT
      BASIC(20)=YFRONT
      BASIC(21)=ANGFRT
      BASIC(22)=QFRONT
      BASIC(23)=APPLE
```

```
C     CALCULATE VALUE OF ISLOPE
      I=0
   96 I=I+1
      IF(I.LT.NC)GO TO 98
      CALL ERASE
      CALL SENDHS(' DATA ERROR : FIRST BACKFILL COORDINATE DOES NOT')
      CALL SENDHS(' CORRESPOND TO ANY WALL COORDINATE')
      GO TO 10007
   98 IF(WX(I).NE.SX(1).OR.WY(I).NE.SY(1))GO TO 96
      ISLOPE=I


C     DATA CHECK
  141 CALL ERASE
      CALL SENDHS('DATA CHECK REQUIRED ?')
      CALL CURSOR(JC,ICX,ICY)
      IF(JC.EQ."116)GO TO 49
      IF(JC.NE."131)GO TO 141
      CALL MOVETO(250,755,IDUM,0,1)
      CALL HOLSTR('*** DATA CHECK ***')
      CALL DATOUT
      CALL MOVETO(10,80,IDUM,0,1)
      CALL HOLSTR('DATA CHANGE REQUIRED ?')
      CALL DEPICT(IDFILE,1)
  142 CALL CURSOR(JC,ICX,ICY)
      IF(JC.EQ."116)GO TO 49
      IF(JC.NE."131)GO TO 142
      CALL SENDHS('.')
      CALL ERASE
      CALL DATACH


C     AUTOMATIC FORMATION OF DATA FILE
   49 IF(.NOT.MANDAT)GO TO 125
   50 CALL ERASE
      CALL SENDHS('DO YOU WANT DATA FILE CREATED ? ')
      CALL CURSOR(JC,ICX,ICY)
      IF(JC.EQ."116)GO TO 125
      IF(JC.NE."131)GO TO 50
      CALL ERASE
      CALL SENDHS('NAME FOR DATA FILE :')
      CALL KILLLF
      CALL READCS(ID,5,IDUM)
      CALL OFILE(1,ID)
      WRITE(1,100) NC
      WRITE(1,100) ISLOPE
      DO 122 I=1,NC
  122 WRITE(1,110) WX(I),WY(I)
      WRITE(1,100) NSC
      DO 123 I=1,NSC
  123 WRITE(1,110) SX(I),SY(I)
      WRITE(1,110)PB1,PB2
      WRITE(1,110) QS,QWS
      WRITE(1,110)CB,CA
      WRITE(1,110) QFS,QWFS
      WRITE(1,110) Q0,QNCMAX
```

```
      WRITE(1,115) CFOUND
      WRITE(1,110) XFRONT,YFRONT
      WRITE(1,115) WATERB
      WRITE(1,110) TBASE,TSTEM
      WRITE(1,120) DFSTIP,DFSLID,DFSBCY
      WRITE(1,115) HFRONT


      DO 124 I=1,NSC1
  124 WRITE(1,115) SURCH(I)
      WRITE(1,115) WALDEN
      MANDAT=.FALSE.



C     **** SPECIFICATION OF DESIGN FACTORS ****

C     UNITS : METRIC OR IMPERIAL
  125 CALL ERASE
      CALL SENDHS('UNITS : M(ETRIC) OR I(MPERIAL) ?')
      CALL KILLLF
      CALL CURSOR(JC,ICX,ICY)
      IF(JC.EQ."115)GO TO 35
      IF(JC.NE."111)GO TO 125
C     IMPERIAL UNITS : SET CONSTANT TERMS
      PWATER=62.4
      BASLIM=4.0
      DEPTHB=2.00
      BASEBC=3.00
      GO TO 128
C     METRIC UNITS : SET CONSTANT TERMS
   35 PWATER=9.81
      BASLIM=1.0
      DEPTHB=1.00
      BASEBC=1.00



C     WEIGHT OF SOIL ABOVE TOE
  128 CALL ERASE
      CALL SENDHS('.')
      CALL SENDHS('SOIL WEIGHT ABOVE TOE TO BE INCLUDED IN DESIGN ? ')
      CALL KILLLF
      CALL CURSOR(JC,ICX,ICY)
      TOEFCT=0.0
      IF(JC.NE."131.AND.JC.NE."116)GO TO 128
      IF(JC.EQ."131)TOEFCT=1.0


C     PASSIVE PRESSURE PERCENTAGE
  129 CALL ERASE
      CALL SENDHS(' WHAT % OF PASSIVE PRESSURE CAN BE USED ?')
      CALL KILLLF
      CALL SENDRL(APPLE,0,0,.TRUE.)
      IF(APPLE.LT.0.0.OR.APPLE.GT.100.00)GO TO 129
      APPLE=APPLE/100.00


C     WATER IN TENSION CRACK
```

```
  133 CALL ERASE
      DRAIN1=0.0
      DRAIN2=0.0
      GO TO 136
      CALL SENDIN(IDUM,0,.FALSE.)
      CALL SENDHS('IS WALL BACK DRAINED ?')
      CALL CURSOR(JC,ICX,ICY)
      DRAIN1=1.0
      DRAIN2=0.0
      IF(JC.NE."131.AND.JC.NE."116)GO TO 133
      IF(JC.EQ."131)GO TO 136
      DRAIN1=0.0
      DRAIN2=1.0

C     PROVISION OF KEY
  136 CALL ERASE
      CALL SENDHS('DO YOU WANT WALL KEY ? :')
      CALL KILLLF
      CALL CURSOR(JC,ICX,ICY)
      IF(JC.NE."131.AND.JC.NE."116)GO TO 136
      IF(JC.EQ."116)GO TO 140
      CALL ERASE
      CALL KEYS



C     **** SELECTION OF ANALYSIS METHOD ***

C     SIMPLE OR INCLUDED WEDGE ANALYSIS
  140 CALL ERASE
      CALL SENDHS('METHOD FOR CANTILEVER ANALYSIS :-')
      CALL SENDHS('.')
      CALL SENDHS('INCLUDED WEDGE')
      CALL SENDHS('SIMPLE')
      CALL MENUIN(LOGF,1)
      CALL INSERT('       1',8)
      CALL INSERT('       2',8)
      CALLCURSOR(JC,ICX,ICY)
      KEY=IPOSN(ICY)
      SIMPLE=.FALSE.
      IF(KEY.EQ.2)SIMPLE=.TRUE.



C     MANUAL OR AUTOMATIC ANALYSIS FOR CANTILEVER WALLS
  143 CALL ERASE
      CALL SENDHS('IS AUTOMATIC CANTILEVER DESIGN REQUIRED ?')
      CALL CURSOR(JC,ICX,ICY)
      MANUAL=.TRUE.
      IF(JC.NE."131.AND.JC.NE."116)GO TO 143
      IF(JC.EQ."131)MANUAL=.FALSE.
      IF(JC.EQ."116)GO TO 144
```

```
C     **** INPUT DATA FOR AUTOMATIC CANTILEVER DESIGN ****

C     DATA INPUT
  146 CALL ERASE
      MANUAL=.FALSE.
      CALL SENDHS('**AUTOMATIC CANTILEVER ANALYSIS**')
      CALL SENDHS('HOW MANY TOE DEPTHS ? :')
      CALL KILLLF
      CALL SENDIN(NTOED,0,LOG)
      CALL SENDHS('TOE DEPTH INCREMENT :')
      CALL KILLLF
      CALL SENDRL(DELTOE,0,0,LOG)
      CALL SENDHS('INITIAL TOE DEPTH VALUE :')
      CALL KILLLF
      CALL SENDRL(TOEDEP,0,0,LOG)
      TOE1=TOEDEP
      TOEDEP=TOEDEP-DELTOE
      CALL SENDHS('INITIAL BASE WIDTH :')
      CALL KILLLF
      CALL SENDRL(BSTART,0,0,LOG)
      CALL SENDHS('BASE INCREMENT :')
      CALL KILLLF
      CALL SENDRL(DELTAB,0,0,LOG)
      CALL SENDHS('NUMBER OF RATIOS TO BE CONSIDERED :')
      CALL KILLLF
      CALL SENDIN(NRATIO,0,LOG)
      DO 147 I=1,NRATIO
      CALL SENDHS('RATIOS(')
      CALL KILLLF
      CALL SENDIN(I,1,LOGF)
      CALL KILLLF
      CALL SENDHS(') :')
      CALL KILLLF
     CALL SENDRL(A,0,0,LOG)
  147 RATIOS(I)=A
      NOA=0

C     CHECK RATIOS() ARRAY IS IN ASCENDING ORDER
      N=NRATIO
      IF(N.EQ.1)GO TO 144
      N1=N-1
      DO 14710 J=1,N1
      N2=N-J
      DO 14710 I=1,N2
      IF(RATIOS(I).LT.RATIOS(I+1))GO TO 14710
      A=RATIOS(I+1)
      RATIOS(I+1)=RATIOS(I)
      RATIOS(I)=A
14710 CONTINUE


C     **** SET VARIABLES TO INITIAL VALUES ****

  144 BASTOP=HFRONT
      PABASE=0.0
      PABOT=0.0
      SHEEL=0.0
```

```
      TCSURW=0.0
      BASLOW=2.0*TSTEM
      WEDANG=0.0
      KOUNTS=0
      NOWEDG=WEDGNO-1
      TANQS=SIN(QS)/COS(QS)
      SLOPEF=SIN(ANGFRT)/COS(ANGFRT)
      CFRONT=YFRONT-SLOPEF*XFRONT
      OVMIN=10000.00
      OVMAX=-10000.00
      IRES=0
      ADHTOP=0.0
      ADHANG=0.0
      SIMON=.FALSE.
      IF(MANUAL)GO TO 149


C     **** AUTOMATIC CANTILEVER DESIGN : ESTABLISH WALL COORDS ****

C     ESTABLISH FIXED COORDINATES
      BACK=1.0
      ISLOPE=5
      NC=8
      NOTOE=0
      WX(4)=SX(1)-TSTEM
      WY(4)=SY(1)
      WX(5)=SX(1)
      WY(5)=SY(1)
      WX(3)=SX(1)-TSTEM
      WX(6)=SX(1)
      YWLFRT=SLOPEF*WX(3)+CFRONT

C     ESTABLISH COORDINATES WHICH VARY WITH TOE DEPTH
 3400 NOTOE=NOTOE+1
      TOEDEP=TOEDEP+DELTOE
      H=HFRONT+TOEDEP
      WY(1)=SY(1)-H
      WY(2)=WY(1)+TBASE
      WY(3)=WY(2)
      WY(6)=WY(2)
      WY(7)=WY(2)
      WY(8)=WY(1)
      NORAT=0
 3405 BASE=BSTART
      NANT=0
      NATOT=0
      NORAT=NORAT+1
      RATIO=RATIOS(NORAT)

C     ESTABLISH COORDINATES WHICH VARY WITH TOE:BASERATIO
 3410 TOEL=BASE*RATIO
      IF(TOEL.LT.TSTEM)TOEL=TSTEM
      NANT=NANT+1
      NATOT=NATOT+1
      WX(1)=SX(1)-TOEL
      WX(2)=WX(1)
```

```
      WX(7)=WX(1)+BASE
      WX(8)=WX(7)
      ANGBAS=PYE2
      CRACK=.FALSE.


C     **** EXAMINE FRONT OF WALL CONDITIONS ****

C     FIND WHERE GROUND IN FRONT OF WALL MEETS WALL
  149 BASE=SQRT((WX(NC)-WX(1))**2+(WY(NC)-WY(1))**2)
      I=0
  150 I=I+1
      IF(WY(I+1).EQ.WY(I))GO TO 153
      IF(WX(I+1).NE.WX(I))GO TO 151

C     (1) WALL ELEMENT VERTICAL
      XWLFRT=WX(I)
      YWLFRT=SLOPEF*XWLFRT+CFRONT
      GO TO 152

C     (2) WALL ELEMENT INCLINED
  151 T=(WY(I+1)-WY(I))/(WX(I+1)-WX(I))
      CWALL=WY(I)-T*WX(I)
      YWLFRT=(CWALL*SLOPEF-CFRONT*T)/(SLOPEF-T)
      XWLFRT=(YWLFRT-CWALL)/T
  152 IF(YWLFRT.GT.WY(I+1))GO TO 150
      GO TO 154

C     (3) WALL ELEMENT HORIZONTAL
  153 YWLFRT=WY(I)
      IF(SLOPEF.NE.0.0)GO TO 156
      IF(YFRONT.NE.WY(I))GO TO 150
      XWLFRT=WX(I)
      GO TO 154
  156 XWLFRT=(WY(I)-CFRONT)/SLOPEF
      IF(XWLFRT.LE.WX(I).OR.XWLFRT.GE.WX(I+1))GO TO 150

  154 WTOE=0.0
      XWTOE=0.0
      IF(I.EQ.1)GO TO 170
      IF(TOEFCT.EQ.0.0)GO TO 165

C     CALCULATION OF WEIGHT OF SOIL ABOVE TOE
      A=QFRONT/PB1
      DO 155 J=1,I
      XTOP(J)=WX(J)
      YBOT(J)=WY(J)
  155 YTOP(J)=A+YWLFRT+SLOPEF*(XWLFRT-WX(J))
      NTOP=I+1
      XTOP(NTOP)=XWLFRT
      YTOP(NTOP)=YWLFRT+A
      YBOT(NTOP)=YWLFRT
  160 WATER=WATERF
```

```
      UP=0.0
      CALL WEIGHT
      XWTOE=0.0
      WTOE=SUMWT
      IF(WTOE.GT.0.0)XWTOE=SUMMTY/SUMWT



C     **** RANKINES METHOD FOR PASSIVE PRESSURES ****

C     CALCULATE PASSIVE PRESSURE IGNORING ANY KEY
  165 PASIVE=0.0
      PASKEY=0.0
      YPASE=0.0
      IF(APPLE.EQ.0.0)GO TO 300
      COSA=COS(ANGFRT)
      H=SLOPEF*WX(1)+CFRONT-WY(1)
      A=SQRT(COSA**2-COS(QS)**2)
      A=COSA*(COSA+A)/(COSA-A)
      PASIVE=(0.5*PB1*(H**2)*A)*APPLE
      PASIVQ=H*APPLE*(QFRONT*A+2.0*CB*SQRT(A))
      APASE=ANGFRT
      XPASE=WX(1)
      YPASE=0.0
      IF(PASIVE.EQ.0.0.AND.PASIVQ.EQ.0.0)GO TO 168
      YPASE=WY(1)+(PASIVE*H/3.0+PASIVQ*H/2.0)/(PASIVE+PASIVQ)
  168 PASIVE=PASIVE+PASIVQ
      PASKEY=PASIVE
      IF(DEPKEY.EQ.0.0)GO TO 300

C     CALCULATE PASSIVE PRESSURE FOR KEY
      H=H+DEPKEY+(WY(NC-1)-WY(NC)-WY(2)+WY(1))
      PASKEY=0.5*PB1*(H**2)*A*APPLE
      PQSKEY=H*APPLE*(QFRONT*A+2.0*CB*SQRT(A))
      YPSKEY=(WY(NC)-DEPKEY)+(PASKEY*H/3.0+PQSKEY*H/2.0)/(PASKEY+PQSKEY)
      PASKEY=PASKEY+PQSKEY
      GO TO 300



C     **** FRICTION CIRCLE CALCULATION OF PASSIVE FORCE ****
  170 PASIVE=0.0
      XPASE=0.0
      YPASE=0.0
      APASE=0.0
      IF(APPLE.EQ.0.0)GO TO 300
      IF(YWLFRT.EQ.WY(1))GO TO 300
      CALL FRICLE
      PASIVE=PASIVE*APPLE



C     **** CONSIDER WALL FACTORS ****

C     CALCULATE WEIGHT AND LINE OF COG OF WALL
  300 WMMTY=0.0
```

```
      WAREA=0.0
      NC1=NC-1
      SBASE=(WY(1)-WY(NC))/(WX(1)-WX(NC))
      DO 310 I=1,NC1
      XBASE1=WY(1)+SBASE*(WX(I)-WX(1))
      XBASE2=WY(1)+SBASE*(WX(I+1)-WX(1))
      CALL COG(WX(I),WY(I),XBASE1,WX(I+1),WY(I+1),XBASE2)
      WAREA=WAREA+AREA
      WMMTY=WMMTY+AMMTY
  310 CONTINUE
      WWALL=WAREA*WALDEN
      WALLX=WMMTY*WALDEN/WWALL

C     CALCULATE ANGLE OF WALL BASE
      AGBASE=0.0
      A=WY(1)-WY(NC)
      IF(A.NE.0.0)AGBASE=ATAN(A/(WX(NC)-WX(1)))



C     **** CONSIDER TENSION CRACKS ****

C     CALCULATION OF DEPTH OF TENSION CRACK
      CONST=PYE4+(QS/2.00)
      TANANG=SIN(CONST)/COS(CONST)
      H0=2.0*CB*TANANG/PB1

C     AMMEND TENSION CRACK IF UNIFORM SURCHARGE PRESENT
      IF(NSC.GT.2.00)GO TO 320
      A=SURCH(1)/PB1
      H0=H0-A
      IF(H0.LT.0.0)H0=0.0
  320 TWATER=TENWAT*PWATER*0.5*H0**2
      XH0=WX(ISLOPE)
      ZH0=WY(ISLOPE)-H0
      IF(ZH0.GT.WY(NC))GO TO 325
      TYPE 322
  322 FORMAT('** TENSION CRACK GREATER THAN WALL HEIGHT')
      PAUSE
      GO TO 10015


C     ESTABLISH POSITION OF TENSION CRACK
  325 IF(H0.LE.0.0)GO TO 1300

C     (1) FIND POSITION OF TENSION CRACK ON WALL BACK
      PRUNE=.FALSE.
      CALL TIGER
      YWATER=ZH0-WY(1)+2.0*H0/3.0
      IF(PRUNE)GO TO 1326

C     (2) ESTABLISH SHAPE OF TOP SURFACE MAKING ALLOWANCE FOR SURCH
      DO 260 I=1,JNO
```

```
      XTOP(I)=SX(I)
  260 YTOP(I)=SY(I)+SURCH(I)/PB1
      I=JNO+1
      XTOP(I)=XH0
      YTOP(I)=ZS+SURCH(JNO)
      NTOP=I

C     (3) ESTABLISH SHAPE OF BOTTOM SURFACE
      J=0
      DO 265 I=ISLOPE,INO
      J=J+1
      XBOT(J)=WX(I)
  265 YBOT(J)=WY(I)
      J=J+1
      XBOT(J)=XH0
      YBOT(J)=ZH0
      NBOT=J

C     (4) CALCULATE WEIGHT OF SOIL WEDGE BETWEEN WALL AND TC
      CALL STRIPS
      WATER=WATERB
      CALL WEIGHT
      TCWEDW=SUMWT
      XTCWED=0.0
      IF(TCWEDW.GT.0.0)XTCWED=SUMMTY/SUMWT
      GO TO 1305

C     NO TENSION CRACK PRESENT
 1300 WALLXX(1)=SX(1)
      WALLYY(1)=SY(1)
      JSTART=1
      INO=ISLOPE

C     **** DETERMINE WALL SHAPE ****

 1305 NO=NC-INO-2
      N=NC
      IF(NO)1310,1313,1318

C     PLANE WALL BACK
 1310 DELTAZ=(DEPKEY+WALLYY(1)-WY(NC))/(2.0*ANLIM)
      DELTOP=DELTAZ
      DELBOT=0.0
      BACK=-1.0
      WSAVEX=WX(NC)
      WSAVEY=WY(NC)-DEPKEY
      NZCTRL=0
      ANGTOP=PYE2
      ANGBOT=PYE2
      IF(WX(NC).EQ.WALLXX(1))GO TO 1312
      ANGTOP=ATAN((WALLYY(1)-WY(NC))/(WX(NC)-WALLXX(1)))
      ANGBOT=ANGTOP
 1312 APATOP=ANGTOP-QWS
```

```
      IF(SIMON)APATOP=ANGSIM
      APABOT=0.0
      ANGLE=ANGTOP
      GO TO 1339

C     BI-PLANAR WALL BACK
 1313 BACK=0.0
 1314 DELTOP=(WALLYY(1)-WY(N-1))/ANLIM
      DELBOT=(WY(N-1)-WY(N))/ANLIM
      DELTAZ=DELTOP
      WSAVEX=WX(N-1)
      WSAVEY=WY(N-1)
      ANGTOP=PYE2
      IF(WALLXX(1).EQ.WX(N-1))GO TO 1315
      ANGTOP=ATAN((WALLYY(1)-WY(N-1))/(WX(N-1)-WALLXX(1)))
 1315 ANGBOT=PYE2
      IF(WX(N).EQ.WX(N-1))GO TO 1316
      ANGBOT=ATAN((WY(N-1)-WY(N))/(WX(N)-WX(N-1)))
 1316 NZCTRL=0
      ANGLE=ANGTOP
      APATOP=ANGTOP-QWS
      APABOT=ANGBOT-QWS
      CTERM=CA
      GO TO 1339

C     TRI-PLANAR WALL BACK
C     (1) CHECK SLOPES OF TOP TWO ELEMENTS
 1318 SLOPE1=100000.0
      IF(WX(ISLOPE).EQ.WX(ISLOPE+1))GO TO 1319
      SLOPE1=(WY(ISLOPE)-WY(ISLOPE+1))/(WX(ISLOPE+1)-WX(ISLOPE))
 1319 SLOPE2=100000.0
      IF(WX(ISLOPE+1).EQ.WX(ISLOPE+2))GO TO 13190
      SLOPE2=(WY(ISLOPE+1)-WY(ISLOPE+2))/(WX(ISLOPE+2)-WX(ISLOPE+1))
13190 IF(SLOPE2.LT.SLOPE1)GO TO 1321
      BACK=1.0
      N=NC-1
      GO TO 1314

C     (2) CHECK SLOPE2 WITH TAN(QS)
 1321 YTAN=WY(ISLOPE+1)
      IF(SLOPE2.GE.TANQS)GO TO 1327

C     (3) CHECK TO SEE IF INCLUDED WEDGE APPLICABLE
 1330 JSTART=1
      I1=ISLOPE+1
      NC1=NC-1
      IF(WX(ISLOPE).EQ.WX(I1))GO TO 1325
      A=(WY(ISLOPE)-WY(I1))/(WX(ISLOPE)-WX(I1))
      C=WY(ISLOPE)-A*WX(ISLOPE)
      C1=WY(NC1)+TANQS*WX(NC1)
      YTAN=(TANQS*C+A*C1)/(TANQS+A)
      GO TO 1326
 1325 YTAN=WY(NC1)+TANQS*(WX(NC1)-WX(ISLOPE))

 1326 IF(ZH0.GT.YTAN)GO TO 1327
```

```
      TYPE 13260
13260 FORMAT('** TENSION CRACK TOO LARGE : TRY RUNNING SIMPLE ')
      PAUSE
      GO TO 140


C     CHECK WHETHER INCLUDED WEDGE ANALYSIS APPLICABLE
 1327 IF(.NOT.SIMPLE)GO TO 13279


C     **** SIMPLE ANALYSIS ****

C     CALCULATE INTERSECTION OF VERTICAL THRO HEEL
      SIMON=.TRUE.
      I=0
      SHEEL=0.0
      AMHEEL=0.0
13270 I=I+1

C     KEEP RECORD OF MAGNITUDE AND MOMENT OF SURCHARGE ABOVE HEEL
      A=SQRT((SX(I+1)-SX(I))**2+(SY(I+1)-SY(I))**2)
      IF(A.EQ.0.0)A=1.0
      DELSUR=A*SURCH(I)
      SHEEL=SHEEL+DELSUR
      AMHEEL=AMHEEL+DELSUR*(SX(I)+0.5*(SX(I+1)-SX(I)))
      IF(WX(NC).GT.SX(I+1))GO TO 13270
      YHEEL=SY(I+1)
      IF(WX(NC).EQ.SX(I+1))GO TO 13272
      YHEEL=SY(I)+(WX(NC)-SX(I))*(SY(I+1)-SY(I))/(SX(I+1)-SX(I))
      A=SQRT((SY(I+1)-YHEEL)**2+(SX(I+1)-WX(NC))**2)
      DELSUR=A*SURCH(I)
      SHEEL=SHEEL-DELSUR
      AMHEEL=AMHEEL-DELSUR*(WX(NC)+0.5*(SX(I+1)-WX(NC)))

C     FORM XTOP() YTOP() ARRAYS
13272 JSTART=I+1
      DO 13274 J=1,I
      XTOP(J)=SX(J)
13274 YTOP(J)=SY(J)
      I=I+1
      XTOP(I)=WX(NC)
      YTOP(I)=YHEEL
      NTOP=I

C     FORM XBOT() YBOT() ARRAYS
      I=0
      DO 13276 J=ISLOPE,NC
      I=I+1
      XBOT(I)=WX(J)
13276 YBOT(I)=WY(J)
      I=I+1
      XBOT(I)=WX(NC)
      YBOT(I)=YHEEL
      NBOT=I
```

```
C       CALCULATE SOIL WEIGHT ABOVE HEEL
        CALL STRIPS
        WATER=WATERB
        UP=0.0
        CALL WEIGHT

C       MAKE ALLOWANCE FOR ANY SURCHARGES
        SWWT=SUMWT+SHEEL
        SWXBAR=(SUMMTY+AMHEEL)/SWWT

C       CALCULATE ANGLE OF PATOP
        ANGSIM=PYE2
        D=SY(2)-SY(1)
        IF(D.NE.0.0)ANGSIM=ATAN((SX(2)-SX(1))/D)
        IF(NSC.EQ.2)GO TO 13278
        A=2.0*(WY(ISLOPE)-WY(NC))+WX(ISLOPE)
        I=0
13277   I=I+1
        IF(A.GT.SX(I+1))GO TO 13277
        Y=SY(I)+(A-SX(I))*(SY(I+1)-SY(I))/(SX(I+1)-SX(I))
        ANGSIM=PYE2
        DELTA=Y-WY(ISLOPE)
        IF(DELTA.GT.0.)ANGSIM=ATAN((A-WX(ISLOPE))/DELTA)
13278   WALLXX(1)=WX(NC)
        WALLYY(1)=YHEEL-H0
        GO TO 1310

C       **** SPECIFICATION FOR INCLUDED WEDGE ****

13279   DLTAZ1=(ZH0-YTAN)/WEDGNO
        BACK=1.0
        CTERM=CA
        Z1=ZH0
        KOUNT=0
        KOUNTM=0
        WALLXX(1)=XH0
        WALLYY(1)=ZH0
        ANGTOP=PYE2
        IF(WX(ISLOPE).EQ.WX(ISLOPE+1))GO TO 1331
        ANGTOP=ATAN((WY(ISLOPE)-WY(ISLOPE+1))/(WX(ISLOPE+1)-WX(ISLOPE)))

C       **** INCREMENTATION OF INCLUDED WEDGE ****

 1331   Z1=Z1-DLTAZ1
        CTRLTP=0.00
        KOUNT=KOUNT+1
        NOBC=2
        FACTOR=(WX(ISLOPE+1)-WALLXX(1))/(WY(ISLOPE+1)-WALLYY(1))
        X=WX(ISLOPE+1)+FACTOR*(Z1-WY(ISLOPE+1))
        WSAVEX=X
```

```
      WSAVEY=Z1
      ANGBOT=ATAN((WSAVEY-WY(NC-1))/(WX(NC-1)-WSAVEX))
      WEDANG=ANGBOT
      ANGLE=ANGTOP
      APATOP=ANGTOP-QWS
      APABOT=ANGBOT-QS
      IF(KOUNT.EQ.6.AND.SLOPE2.GE.TANQS)CTERM=CA


C     **** SPECIFICATION FOR GRAPHIC DIFFERENTIATION ****

 1320 DELTAZ=(WALLYY(1)-WSAVEY)/ANLIM
      DELTOP=DELTAZ
      DELBOT=(WSAVEY-WY(NC-1))/ANLIM
      NZCTRL=0
 1339 Z=WALLYY(1)
      TOPSC=0.0
      TOPSPA=0.0


C     **** INCREMENTATION FOR GRAPHIC DIFFERENTIATION ****
 1340 Z=Z-DELTAZ
      NZCTRL=NZCTRL+1
      IF(BACK.EQ.-1.0)GO TO 1342
      IF(NZCTRL.EQ.NLIM1)Z=WSAVEY
      IF(NZCTRL.GT.NLIM1.AND.DELBOT.EQ.0.0)GO TO 1346
      IF(Z.GE.WSAVEY)GO TO 1342

C     WALL BACK HAS BREAK
 1341 NO=2
      WALLXX(2)=WSAVEX
      WALLYY(2)=WSAVEY
      WALLXX(3)=WX(ISLOPE+2)
      WALLYY(3)=WY(ISLOPE+2)
      ADCTRL=0.0
      GO TO 1344

C     WALL BACK PLANE
 1342 NO=1
      WALLXX(2)=WSAVEX
      WALLYY(2)=WSAVEY
      ADCTRL=-1.0

C     CALCULATE COORDINATES OF EFFECTIVE WALL BASE
 1344 X=WALLXX(NO)+(WALLYY(NO)-Z)*(WALLXX(NO+1)-WALLXX(NO))/
     1  (WALLYY(NO)-WALLYY(NO+1))
      NO=NO+1
      WALLXX(NO)=X
      WALLYY(NO)=Z
      NOBC=NO
      GO TO 1360
```

```
C     WALL BACK ELEMENT HORIZONTAL
 1346 DELTAH=(WX(ISLOPE+2)-WX(ISLOPE+1))/NLIM1
      NO=3
      WALLXX(2)=WSAVEX
      WALLYY(2)=WSAVEY
      N=NZCTRL-NLIM1
      AN=N
      WALLXX(3)=WSAVEX+DELTAH*AN
      ADCTRL=0.0
      CTERM=CA
      NOBC=3
      GO TO 1360


C     **** TRIAL WEDGE ANALYSIS ****

C     SET ANGLE OF WEDGE BASE, S
 1360 S=PYE2
 1361 DELTAS=PYE18
      PASAVE=-100000.0
      ANGPA=0.0
      PA=-100000.0
      C=ANGLE-QWS
      IF(SIMON)C=ANGSIM
      IF(BACK.LT.1.0)GO TO 1369
      IF(ANGLE.EQ.ANGBOT)C=ANGLE-QS
 1369 PASAVE=PA
      ANSAVE=ANGPA
 1370 S=S-DELTAS
      IF(S.GT.QS)GO TO 1390
      PA=0.0
      GO TO 1800
 1390 SURWT=0.0
      TANS=SIN(S)/COS(S)

C     FIND WHERE WEDGE BASE CUTS GROUND SURFACE AND VALUE OF SURWT
      I=0
 1400 I=I+1
      IF(SX(I+1).NE.SX(I))GO TO 1407

C     SURFACE ELEMENT VERTICAL
      X=SX(I)
      Y=TANS*(X-WALLXX(NOBC))+WALLYY(NOBC)
      SURWT=SURWT+SURCH(I)
      IF(SY(I+1).GT.SY(I))GO TO 1400
      IF(Y.LT.SY(I+1).OR.Y.GT.SY(I))GO TO 1400
      GO TO 1408

C     NON-VERTICAL SURFACE ELEMENT
C     (1) CALCULATE SURCHARGE ON ELEMENT
 1407 ALEN=SQRT((SX(I+1)-SX(I))**2+(SY(I+1)-SY(I))**2)
      IF(ALEN.LT.0.001)ALEN=1.0
      DELTAW=SURCH(I)*ALEN
      SURWT=SURWT+DELTAW
```

```
C      (2) CHECK SURFACE SLOPE NOT PARALLEL TO WEDGE BASE
       A=(SY(I+1)-SY(I))/(SX(I+1)-SX(I))
       DELTA=ABS(TANS-A)
       IF(DELTA.LT.0.000001)GO TO 1400
       IF(A.NE.0.0)GO TO 1405

C      (3) HORIZONTAL ELEMENT
       Y=SY(I)
       X=WALLXX(NOBC)+(Y-WALLYY(NOBC))/TANS
       GO TO 1406

C      (4) SLOPING ELEMENT
 1405  Y=(A*WALLYY(NOBC)-TANS*SY(I)+(A*TANS*(SX(I)-WALLXX(NOBC))))/
     1  (A-TANS)
       X=SX(I)+(Y-SY(I))/A

C      CHECK VALIDITY OF INTERSECTION
 1406  IF((I+1).EQ.NSC)GO TO 14060
       IF(X.LT.SX(I).OR.X.GT.SX(I+1))GO TO 1400

C      ADJUST SURCHARGE TOTAL
14060  ALEN=SQRT((SX(I+1)-X)**2+(SY(I+1)-Y)**2)
       WDASH=SURCH(I)*ALEN
       SURWT=SURWT-SHEEL-WDASH-TCSURW
 1408  XSUR=X
       YSUR=Y
       JEND=I
       IF(H0.EQ.0.0)GO TO 1461

C      AMEND SURWT TO TAKE ACCOUNT OF TENSION CRACK
       IA=I
       CALL CRACKS

C      CALCULATE TRIAL WEDGE WEIGHT
C      (1) ESTABLISH SHAPE OF BOTTOM SURFACE
 1461  DO 1500 K=1,NOBC
       XBOT(K)=WALLXX(K)
 1500  YBOT(K)=WALLYY(K)
       Y=YSUR-H0
       K=NOBC+1
       XBOT(K)=XSUR
       YBOT(K)=Y
       IF(H0.EQ.0.0)GO TO 1505
       K=K+1
       XBOT(K)=XSUR
       YBOT(K)=YSUR
 1505  NBOT=K

C      (2) ESTABLISH SHAPE OF TOP SURFACE
       K=0
C      CHECK FOR SIMPLE ANALYSIS
       IF(.NOT.SIMON)GO TO 1540
```

```
      XTOP(1)=WX(NC)
      YTOP(1)=YHEEL
      K=1
      IF(JSTART.EQ.JEND)GO TO 1565
      GO TO 1545

 1540 IF(MANUAL.EQ.LOGF)GO TO 1550
      IF(H0.EQ.0.0)GO TO 1550
      K=1
      XTOP(1)=XH0
      YTOP(1)=ZS
 1545 IF(JEND.LT.JSTART)GO TO 1565
 1550 DO 1560 J=JSTART,JEND
      K=K+1
      XTOP(K)=SX(J)
 1560 YTOP(K)=SY(J)
 1565 K=K+1
      XTOP(K)=XSUR
      YTOP(K)=YSUR
      NTOP=K

C     (3) CALCULATE WEIGHT
      CALL STRIPS
      WATER=WATERB
      UP=1.0
      CALL WEIGHT

C     CALCULATION OF RESULTANT ACTIVE PRESSURE
C     CALCULATE COHESION FORCE
      AL=SQRT((XSUR-WALLXX(NOBC))**2+(YSUR-H0-WALLYY(NOBC))**2)
      COHESN=AL*CB

C     CALCULATE ADHESION FORCE
      FANGLE=0.0
      ADHESN=0.0
      IF(SIMON)GO TO 424
      IF(ADCTRL)421,422,423

C     (A) TOP WALL SECTION
  421 ADHESN=0.0
      IF(Z.GE.ZH0)GO TO 424
      ALEN=SQRT((WALLYY(1)-WALLYY(2))**2+(WALLXX(2)-WALLXX(1))**2)
      ADHESN=CA*ALEN
      FANGLE=ANGTOP
      GO TO 424

C     (B) MIDDLE WALL SECTION OR INCLUDED WEDGE
  422 ALEN=SQRT((WALLYY(2)-WALLYY(3))**2+(WALLXX(2)-WALLXX(3))**2)
      ADHESN=CTERM*ALEN
      FANGLE=ANGBOT
      GO TO 424

C     (C) BASE SECTION
```

```
  423 ALEN=SQRT((WALLYY(4)-WALLYY(3))**2+(WALLXX(4)-WALLXX(3))**2)
      ADHESN=ALEN*CA
      FANGLE=ANGBAS

C     CALCULATION OF PA
  424 A=PYE2-S
      B=S-QS
      SUMWT=SUMWT+SURWT
      PART1= SIN(B)*(SUMWT-COS(A)*COHESN-SIN(FANGLE)*ADHESN
     1       -TOPSPA*COS(TOPSC)-ADHTOP*SIN(ADHANG))
      PART2= COS(B)*(COHESN*SIN(A)-ADHESN*COS(FANGLE)+TOPSPA*SIN(TOPSC)-
     1       -TWATER*DRAIN1-ADHTOP*COS(ADHANG))
      ANUM=PART1-PART2
      DENOM=COS(C)*SIN(B)+COS(B)*SIN(C)
      ANGPA=C
      PA=ANUM/DENOM
      FREACT= (COHESN*SIN(A)+PA*SIN(C)+TOPSPA*SIN(TOPSC)
     1        -ADHESN*COS(FANGLE)-TWATER*DRAIN1
     1        -ADHTOP*COS(ADHANG))/SIN(B)

C     CHECK VALUE OF PA
      IF(PA.LT.0.0)PA=-100000.0
      IF(FREACT.LT.0.0)PA=-100000.0
      IF(PA.GE.PASAVE)GO TO 1369
      IF(DELTAS.EQ.PYE180)GO TO 1800


 1790 S=S+2.0*(DELTAS)
      DELTAS=PYE180
      PASAVE=-100000.0
      GO TO 1370



C     ****ASCERTAIN CURRENT POSITION OF ANALYSIS PROCESS ****

 1800 IF(THIRD)GO TO 1861
      IF(NZCTRL.NE.NLIM1)GO TO 1833
      IF(BACK)1833,1805,1805

C     TRANSFER RESULTS OF TOP ANALYSIS TO TOPSPA : PROCEED WITH BOTTOM
 1805 IF(PASAVE.LT.0.0)PASAVE=0.0
      TOPSPA=PASAVE
      TOPSC=C
      NOBC=3
      ANGLE=ANGBOT
      DELTAZ=DELBOT
      ADHTOP=ADHESN
      ADHANG=ANGTOP


 1833 IF(FREACT.LT.0.0)PASAVE=0.0
      IF(PASAVE.LT.0.0)PASAVE=0.0
      ACTIVE(NZCTRL)=PASAVE
      IF(NZCTRL.NE.NLIM2)GO TO 1340
      IF(BACK.LE.0.0)GO TO 1870
```

```
      IF(SLOPE2.GE.SLOPE1)GO TO 1860

C     CALCULATION OF  WEIGHT OF INCLUDED SOIL WEDGE
      WSAVEY=Z1
      WSAVEX=WALLXX(1)
      A=WX(ISLOPE)-WX(ISLOPE+1)
      I=ISLOPE
      IF(A.NE.0.)WSAVEX=WX(I)+(WSAVEY-WY(I))*A/(WY(I)-WY(I+1))
      Y=WSAVEY+(WX(I+1)-WSAVEX)*(WY(NC-1)-WSAVEY)/(WX(NC-1)-WSAVEX)
      IF(WSAVEY.GT.WY(ISLOPE+1))GO TO 1828
      SWWT=0.00
      SWXBAR=0.00
      WALLX3=WALLXX(3)
      WALLY3=WALLYY(3)
      GO TO 1860
 1828 XTOP(1)=WSAVEX
      XTOP(2)=WX(ISLOPE+1)
      XTOP(3)=WX(NC-1)
      YTOP(1)=WSAVEY
      YTOP(2)=Y
      YTOP(3)=WY(NC-1)
      YBOT(1)=WSAVEY
      YBOT(2)=WY(ISLOPE+1)
      YBOT(3)=YTOP(3)
      NTOP=3
      WALLX3=WALLXX(3)
      WALLY3=WALLYY(3)
      UP=0.0
      CALL WEIGHT
      SWWT=SUMWT
      SWXBAR=SUMMTY/SUMWT


C     **** CALCULATION OF ACTIVE FORCE ON HEEL PROJECTION ****
C     (1)   SET UP INITIAL CONDITIONS
 1860 XISLOP=WX(ISLOPE)
      YISLOP=WY(ISLOPE)
      XNC=WX(NC)
      YNC=WY(NC)
      HORIZ=TOPSPA*SIN(TOPSC)+PASAVE*SIN(C)
      VERT=TOPSPA*COS(TOPSC)+PASAVE*COS(C)
      TOPSPA=SQRT(HORIZ**2+VERT**2)
      TOPSC=ATAN(HORIZ/VERT)
      NOBC=4
      WALLXX(4)=WX(NC)
      WALLYY(4)=WY(NC)-DEPKEY
      NOBC1=NOBC-1
      ANGLE=PYE2
      THIRD=.TRUE.
      D=WALLXX(NOBC)-WALLXX(NOBC1)
      IF(D.GT.0.01)ANGLE=ATAN((WALLYY(NOBC)-WALLYY(NOBC-1))/D)
      ADCTRL=1.0
      HORIZ=ADHTOP*COS(ANGTOP)+ADHESN*COS(ANGBOT)
      VERT=ADHTOP*SIN(ANGTOP)+ADHESN*COS(ANGBOT)
      ADHTOP=SQRT(HORIZ**2+VERT**2)
      ADHANG=0.0
      IF(HORIZ.GT.0.0)ADHANG=ATAN(VERT/HORIZ)
```

```
      GO TO 1360

C     (2)   STORE RESULTS
 1861 THIRD=.FALSE.
      PABASE=PASAVE
      IF(PABASE.LT.0.0)PABASE=0.0
      APABAS=C
      XPABAS=WALLXX(NOBC1)+0.5*(WALLXX(NOBC)-WALLXX(NOBC1))
      YPABAS=WALLYY(NOBC)+0.5*(WALLYY(NOBC1)-WALLYY(NOBC))-WY(1)
      ADHTOP=0.0
      ADHANG=0.0


C     **** ESTABLISH POINT OF APPLICATION OF PATOP PABOT ****
 1870 XISLOP=WX(ISLOPE)
      YISLOP=WY(ISLOPE)
      XNC=WX(NC)
      YNC=WY(NC)
      CALL PAPA


C     **** CALCULATION OF WATER FORCES ****
C     (1) SET ALL FORCES TO ZERO
      PWTOP=0.0
      XPWTOP=0.0
      YPWTOP=0.0
      APWTOP=0.0
      PWBOT=0.0
      XPWBOT=0.0
      YPWBOT=0.0
      APWBOT=0.0
      PWBAS=0.0
      XPWBAS=0.0
      YPWBAS=0.0
      APWBAS=ANGBAS
      IF(WATERB.LE.WALLYY(NOBC))GO TO 807

C     (2) FIND INTERSECTION OF WATER LEVEL AND WALL BACK
      WATER=WATERB
      I=ISLOPE-1
 1875 I=I+1
      IF(WATERB.LT.WY(I+1))GO TO 1875
      IF(WATERB.EQ.WY(I+1))I=I+1
      XWT=WX(I)
      YWT=WATERB
      XWATB=XWT
      YWATB=YWT
      IF(WY(I+1).EQ.WY(I))GO TO 1880
      XWT=WX(I)+(WATERB-WY(I))*(WX(I+1)-WX(I))/(WY(I+1)-WY(I))
      XWATB=XWT

C     (3) CALCULATE WATER FORCE
 1880 XWB=WX(I+1)
```

```
      YWB=WY(I+1)
      CALL AQUA
      IF(NC-I-2)1893,1887,1885

C     (4) ASSIGN VALUE TO TOP WATER FORCE
 1885 PWTOP=PW
      XPWTOP=XPW
      YPWTOP=YPW-WY(1)
      APWTOP=APW
      GO TO 1890

C     (5) ASSIGN VALUE TO BOTTOM WATER FORCE
 1887 PWBOT=PW
      XPWBOT=XPW
      YPWBOT=YPW-WY(1)
      APWBOT=APW
 1890 I=I+1
      XWT=WX(I)
      YWT=WY(I)
      GO TO 1880

C     (6) ASSIGN VALUE TO BASE WATER FORCE
 1893 PWBAS=PW
      XPWBAS=XPW
      YPWBAS=YPW-WY(1)
      APWBAS=APW



C     **** CALCULATION OF FACTORS OF SAFETY ****

C     ESTABLISH FORCE LEVER ARMS
  807 SWXBR1=SWXBAR-WX(1)
      IF(SWXBR1.LT.0.0)SWXBR1=0.0
      XWTOE1=XWTOE-WX(1)
      WALLX1=WALLX-WX(1)
      XTIPT=XPATOP-WX(1)
      XTIPB=XPABOT-WX(1)
      XTIPBS=XPABAS-WX(1)
      XTIPWT=XPWTOP-WX(1)
      XTIPWB=XPWBOT-WX(1)
      XTIPWA=XPWBAS-WX(1)
      YPASE1=YPASE-WY(1)
      XPASE1=XPASE-WX(1)
      XBASE=WX(NC)-WX(1)

C     CALCULATE MAGNITUDE + ECCENTRICITY OF RESULTANT ON BASE
  808 RN=  PATOP*COS(APATOP-AGBASE) + PABOT*COS(APABOT-AGBASE) +
     1      PWTOP*COS(APWTOP-AGBASE) + PWBOT*COS(APWBOT-AGBASE) +
     1      PWBAS*COS(APWBAS-AGBASE) + WWALL*COS(AGBASE) +
     1      PABASE*COS(APABAS-AGBASE) + TWATER*DRAIN2*SIN(AGBASE) +
     1      SWWT*COS(AGBASE) + WTOE*COS(AGBASE)
      RT= PATOP*SIN(APATOP-AGBASE) + PABOT*SIN(APABOT-AGBASE) +
     1    PABASE*SIN(APABAS-AGBASE) + PWTOP*SIN(APWTOP-AGBASE) +
     1    PWBOT*SIN(APWBOT-AGBASE) + PWBAS*SIN(APWBAS-AGBASE) -
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```
     1     WWALL*SIN(AGBASE) + TWATER*DRAIN2*COS(AGBASE)
      R=SQRT(RT**2+RN**2)
      RARM=  WWALL*WALLX1 + SWWT*SWXBR1 + WTOE*XWTOE1 +
     1        PATOP*(COS(APATOP)*XTIPT - SIN(APATOP)*YPATOP) +
     1        PABOT*(COS(APABOT)*XTIPB - SIN(APABOT)*YPABOT) +
     1        PABASE*(COS(APABAS)*XTIPBS - SIN(APABAS)*YPABAS) +
     1        PWTOP*(COS(APWTOP)*XTIPWT - SIN(APWTOP)*YPWTOP) +
     1        PWBOT*(COS(APWBOT)*XTIPWB - SIN(APWBOT)*YPWBOT) +
     1        PWBAS*(COS(APWBAS)*XTIPBA - SIN(APWBAS)*YPWBAS)
     1        -TWATER*DRAIN2*YWATER
      RM=RARM
      RARM=RARM/RN
      E=ABS(BASE*0.5-RARM)
      IF(STORE)GO TO 8080
      XBASE=WX(1)+RARM*COS(AGBASE)
      YBASE=WY(1)-RARM*SIN(AGBASE)


C     FACTOR OF SAFETY AGAINST SLIDING
 8080 IF(STORE)GO TO 809
      S=CFOUND*BASE+RN*SIN(QWFS)/COS(QWFS)
      SLFOR=RT
      STFOR=S+PASKEY*COS(APASE-AGBASE)
      FSLID1=99.00
      IF(SLFOR.GT.0.0)FSLID1=STFOR/SLFOR
      IF(DEPKEY.EQ.0.0)GO TO 811


C     STORE RESULTS FOR FIRST CALCULATION
      S1=AGBASE
      RN1=RN
      E1=E
      BASE1=BASE
      STORE=.TRUE.


C     ESTABLISH EFFECTIVE BASE BETWEEN TOE AND KEY
      DELTAX=WX(NC)-WX(1)-WIDKEY
      DELTAY=WY(1)-WY(NC)+DEPKEY
      BASE=SQRT(DELTAX**2+DELTAY**2)
      AGBASE=ATAN(DELTAY/DELTAX)
      GO TO 808


C     CALCULATE FSLID FOR ALTERNATIVE FAILURE MODE
  809 S=CFOUND*BASE+RN*SIN(QFS)/COS(QFS)
      FSLID2=99.00
      IF(RT.GT.0.0)FSLID2=(S+PASIVE*COS(APASE-AGBASE))/RT
      IF(FSLID1.LT.FSLID2)GO TO 810
      FSLID=FSLID2
      GO TO 812


C     FSLID1 SMALLER RESET TERMS
  810 AGBASE=S1
      RN=RN1
      E=E1
      BASE=BASE1
  811 FSLID=FSLID1
```

```
  812 STORE=.FALSE.


C      FACTOR OF SAFETY AGAINST OVERTURNING
       SM= WWALL*WALLX1 + SWWT*SWXBR1 +
     1    WTOE*XWTOE1 + PASIVE*YPASE1*COS(APASE)
       OM= PATOP*SIN(APATOP)*YPATOP + PABOT*SIN(APABOT)*YPABOT +
     1    PABASE*SIN(APABAS)*YPABAS + PWTOP*SIN(APWTOP)*YPWTOP +
     1    PWBOT*SIN(APWBOT)*YPWBOT + PWBAS*SIN(APWBAS)*YPWBAS
       OM1= PATOP*COS(APATOP)*XTIPT + PABOT*COS(APABOT)*XTIPB +
     1     PABASE*COS(APABAS)*XTIPBS + PWTOP*COS(APWTOP)*XTIPWT +
     1     PWBOT*COS(APWBOT)*XTIPWB + PWBAS*COS(APWBAS)*XTIPWA
       FSTIP=99.ØØ
       IF(OM.GT.Ø.Ø)FSTIP=(SM+OM1)/OM


C      FACTOR OF SAFTEY AGAINST BEARING FAILURE
C      (1) CHECK DEPTH OF BASE
       DEPTH=YWLFRT-WY(1)
       IF(DEPTH.LT.DEPTHB)DEPTH=DEPTHB


C      (2) CHECK POSITION OF RESULTANT ON BASE
       BASE3=BASE/3.Ø
       BASE23=2.Ø*BASE3
       IF(RARM.GE.BASE3.AND.RARM.LE.BASE23)GO TO 21ØØ


C      (3) RESULTANT LIES OUTSIDE MIDDLE THIRD
       ALEN=BASE-2.Ø*E
       IF(ALEN)2Ø92,2Ø94,2Ø95
C      RESULTANT LIES OUTSIDE BASE
 2Ø92  FSBCY=Ø.Ø
       GO TO 2155
C      RESULTANT CUTS EDGE OF BASE
 2Ø94  BPRES=RN
       GO TO 211Ø
C      RESULTANT CUTS OUTSIDE THIRD OF BASE
 2Ø95  BPRES=(4.Ø*RN)/(3.Ø*ALEN)
       GO TO 211Ø


C      (4) COHESIONLESS SOIL MAKE ALLOWANCE FOR BASE WIDTH
 21ØØ  BPRES=RN*(1.Ø+6.Ø*E/BASE)/BASE
 211Ø  IF(CB.GT.Ø.Ø)GO TO 213Ø
       CONST=1.Ø
       IF(BASE.LT.BASEBC)CONST=BASE/BASEBC
       QD=CONST*QØ*(1.Ø+(DEPTH-DEPTHB)/BASE)
       FACTOR=QNCMAX/QØ
       GO TO 214Ø


C      (5) COHESIVE SOIL
 213Ø  QD=QØ*(1.Ø+(DEPTH-DEPTHB)/(4.Ø*BASE))
       FACTOR=1.5
```

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C     (6) ESTABLISH FACTOR OF SAFETY
 2140 QLIM=QNCMAX
      IF(QD.GT.QLIM)QD=QLIM
      FSBCY=QD/BPRES


C     **** MANIPULATION OF FACTORS OF SAFETY ****
 2155 IF(BACK.GT.0.0.AND.SLOPE2.LT.SLOPE1)GO TO 2160
      CRITSL=FSLID
      CRITTP=FSTIP
      CRITBC=FSBCY
      IF(MANUAL)GO TO 10015
      GO TO 3260
 2160 K=KOUNT
      IF(KOUNT.GT.1)GO TO 2175
      CRITTP=FSTIP
      CRITSL=FSLID
      CRITBC=FSBCY
      GO TO 1331
 2175 IF(FSLID.LT.CRITSL)CRITSL=FSLID
      IF(FSTIP.LT.CRITTP)CRITTP=FSTIP
      IF(FSBCY.LT.CRITBC)CRITBC=FSBCY
      IF(KOUNT.LE.NOWEDG)GO TO 1331
      IF(MANUAL)GO TO 10015
      IF(METHOD.EQ.1)GO TO 3260
      KOUNTS=KOUNTS+1
      K=KOUNTS

C     **** AUTOMATIC ANALYSIS : CHECK FACTORS OF SAFETY ****
 3260 IF(CRITTP.LT.DFSTIP)GO TO 3270
      IF(CRITSL.LT.DFSLID)GO TO 3270
      IF(CRITBC.GE.DFSBCY)GO TO 3280
 3270 IF(BASE.GT.BASTOP)GO TO 3271
      BASE=BASE+DELTAB
      GO TO 3410

C     BASE WIDTH EXCEEDS MAXIMUM : CHECK IF SIZE IS ACCEPTABLE
 3271 CALL SENDHS('BASE WIDTH GREATER THAN WALL HEIGHT :')
      CALL KILLLF
      CALL SENDRL(BASTOP,6,2,.FALSE.)
 3272 CALL SENDHS('DO YOU WANT WIDER BASES CONSIDERED ? ')
      CALL CURSOR(JC,ICX,ICY)
      IF(JC.EQ."131)GO TO 3274
      IF(JC.NE."116)GO TO 3272
      GO TO 3280

C     SET NEW LIMIT FOR BASE MAXIMUM
 3274 CALL SENDHS('NEW MAXIMUM VALUE FOR BASE :')
      CALL KILLLF
      CALL SENDRL(BASTOP,6,2,LOG)
      GO TO 3270

C     CHECK NUMBER OF ANALYSES
```

```
 3280 IF(NANT.GT.1)GO TO 3290
      NANT=0
      A=BASE-DELTAB
      IF(A.LE.BASLOW)GO TO 3290
      BASE=A
      GO TO 3410

C     STORE RESULTS FOR OUTPUT AS TABLE
 3290 IRES=IRES+1
      RESTP(IRES)=CRITTP
      RESSL(IRES)=CRITSL
      RESBC(IRES)=CRITBC
      IRESNA(IRES)=NATOT
      RESBAS(IRES)=BASE
      RESRAT(IRES)=RATIO
      RESTD(IRES)=TOEDEP
      RESWAL(IRES)=WWALL
      BASETD(NORAT)=BASE

C     TYPE OUT RESULTS OF LATEST ANALYSIS
      TYPE 10050,CRITTP,CRITSL,CRITBC,TOEDEP,RATIO,BASE,NATOT
10050 FORMAT(F7.2,5F6.2,I15)



C     **** AUTOMATIC ANALYSIS : MANIPULATION OF RESULTS ****

C     FIX VALUE OF BSTART FOR NEXT SECTION ANALYSIS
      BSTART=BASE-DELTAB
      IF(BSTART.LT.BASLOW)BSTART=BASLOW
10054 IF(NORAT.LT.NRATIO)GO TO 3405

C     ANALYSIS COMPLETE FOR CURRENT TOE DEPTH : FIND MINIMUM BASE
      BASMN=1000.00
      BASMX=-1000.00
      DO 10057 I=1,NRATIO
      IF(BASETD(I).LT.BASMX)GO TO 10056
      BASMX=BASETD(I)
10056 IF(BASETD(I).GT.BASMN)GO TO 10057
      BASMN=BASETD(I)
10057 CONTINUE
      BASELO(NOTOE)=BASMN

C     KEEP RECORD OF OVERALL MINIMUM AND MAXIMUM
      IF(BASMN.LT.OVMIN)OVMIN=BASMN
      IF(BASMX.GT.OVMAX)OVMAX=BASMX
      IF(NOTOE.LT.NTOED)GO TO 3400

C     CALL FOR GRAPHICS SUBROUTINE
10015 CALL BLAST
      IF(XXXIT)GO TO 10007
      IF(MANUAL)GO TO 10016
      IF(RERUN)GO TO 146
10016 IF(RERUN)GO TO 40
```

```
C     SUBROUTINE AQUA : CALCULATION OF WATER FORCE


      SUBROUTINE AQUA
      COMMON/BLOCKC/UP,WATER,PB2,PWATER
      COMMON/GROUPE/XWT,YWT,XWB,YWB,PW,XPW,YPW,APW


      ANGLE=1.571
      IF(XWT.EQ.XWB)GO TO 10
      ANGLE=ATAN((YWT-YWB)/(XWB-XWT))
   10 PWT=PWATER*(WATER-YWT)
      PWB=PWATER*(WATER-YWB)
      ALEN=SQRT((XWT-XWB)**2+(YWT-YWB)**2)
      PW=0.5*ALEN*(PWT+PWB)
      ALEN=(ALEN**2)*(2.0*PWT+PWB)/(6.0*PW)
      XPW=XWB-ALEN*COS(ANGLE)
      YPW=YWB+ALEN*SIN(ANGLE)
      APW=ANGLE
      RETURN
      END
```

```
C     SUBROUTINE BORDER : PROVISION OF SURROUND FOR DISPLAY


      SUBROUTINE BORDER
      COMMON IDFILE(2000)
      DIMENSION IDATE(2)
      CALL DATE(IDATE)
      CALL MOVETO(2,779,IDUM,0,1)
      CALL LINE(1017,0,.TRUE.)
      CALL LINE(0,-777,.TRUE.)
      CALL LINE(-1017,0,.TRUE.)
      CALL LINE(0,777,.TRUE.)
      CALL MOVETO(2,56,IDUM,0,1)
      CALL LINE(1017,0,.TRUE.)
      CALL MOVETO(255,56,IDUM,0,1)
      CALL LINE(0,-56,.TRUE.)
      CALL MOVETO(805,56,IDUM,0,1)
      CALL LINE(0,-56,.TRUE.)
      CALL MOVETO(10,20,IDUM,0,1)
      CALL HOLSTR('DATE : ')
      CALL MOVETO(100,20,IDUM,0,1)
      CALL STRING(IDATE,9)
      CALL MOVETO(820,20,IDUM,0,1)
      CALL HOLSTR('TRIAL NO. :')
      END
```

```
C      SUBROUTINE COG : CALCULATION OF AREA AND MOMENT
C                       OF PARALLEL SIDED STRIPS


      SUBROUTINE COG(AX,AY,CY,BX,BY,DY)
      COMMON/BLOCK1/AMMTY,AREA

C     (1) ARRANGE Y-COORDS AT TOP OF ELEMENT
      IF(AY.GT.BY)GO TO 810
      YYTOP1=BY
      YYTOP2=AY
      FACTT=1.0
      GO TO 820
  810 YYTOP1=AY
      YYTOP2=BY
      FACTT=2.0

C     (2) ARRANGE Y-COORDS AT BOTTOM OF ELEMENT
  820 IF(CY.GT.DY)GO TO 830
      YYBOT1=CY
      YYBOT2=DY
      FACTB=2.0
      GO TO 840
  830 YYBOT1=DY
      YYBOT2=CY
      FACTB=1.0

C     (3) CALCULATE AREA AND MOMENTS OF ELEMENT
  840 DELTAX=BX-AX
      DELTAY=YYTOP1-YYBOT1
      DYTOP=YYTOP1-YYTOP2
      DYBOT=YYBOT2-YYBOT1
      AREA=0.5*DELTAX*((AY-CY)+(BY-DY))
      AMMTY=DELTAX*DELTAY*(AX+(0.5*DELTAX))
      CORRN=0.5*DELTAX*(DYTOP*(AX+FACTT*DELTAX/3.0)+
     1      DYBOT*(AX+FACTB*DELTAX/3.0))
      AMMTY=AMMTY-CORRN
      RETURN
      END
```

```
C     SUBROUTINE CRACKS : ASCERTAIN POSITION OF TENSION CRACK
C                         ON TRIAL FAILURE SURFACE



      SUBROUTINE CRACKS
      COMMON/BLOCKI/WALLXX,WALLYY,NOBC,NC,ISLOPE
      COMMON/BLOCKQ/H0,XSAVE,YSAVE,SX,SY,WATERB
      COMMON/BLOCKR/IA,TANS,DELTAW,WDASH,SURWT,SURCH,XSUR,YSUR,XWH0
      COMMON/BLOCKS/X,Y
      COMMON/BLOCKU/JSTART,JEND,ZH0,ZS,XH0
      DIMENSION SURCH(12),SX(12),SY(12),WALLXX(4),WALLYY(4)


      I=IA
      CTRLSU=0.00
      AMB=TANS
      CBOT=WALLYY(NOBC)-TANS*WALLXX(NOBC)
 1410 IF(SX(I).EQ.SX(I+1))GO TO 1455
      AMT=(SY(I+1)-SY(I))/(SX(I+1)-SX(I))
      CT=SY(I+1)-AMT*SX(I+1)
      XWH0=(H0+CBOT-CT)/(AMT-AMB)
      XLOWER=SX(I)
 1411 IF(SX(I).GT.WALLXX(NOBC))GO TO 1412
      XLOWER=WALLXX(NOBC)
 1412 IF(XWH0.GE.XLOWER.AND.XWH0.LE.SX(I+1))GO TO 1440

C      REMOVE SURCHARGE ON ELEMENT CUT BY PLANE WEDGE BASE
      IF(CTRLSU)1415,1415,1420
 1415 SURWT=SURWT-DELTAW+WDASH
      CTRLSU=1.00
      GO TO 1435

C     CALCULATE SURCHARGE ON CURRENT ELEMENT AND REMOVE FROM
C     TOTAL
 1420 ALEN=SQRT((SY(I+1)-SY(I))**2+(SX(I+1)-SX(I))**2)
      IF(ALEN)1425,1425,1430
 1425 ALEN=1.00
 1430 SURWT=SURWT-ALEN*SURCH(I)
 1435 IF(I.GT.1)GO TO 1457

C     TENSION CRACK CUTS FIRST ELEMENT
 1436 SURWT=0.0
      I=0
 1451 I=I+1
      IF(SX(I).EQ.SX(I+1))GO TO 1451
      IF(WALLXX(NOBC).LT.SX(I).OR.WALLXX(NOBC).GT.SX(I+1))GO TO 1451
      AMT=(SY(I+1)-SY(I))/(SX(I+1)-SX(I))
      CT=SY(I+1)-AMT*SX(I+1)
      Y=AMT*WALLXX(NOBC)+CT
      X=WALLXX(NOBC)
      GO TO 1460
```

```
C     CALCULATE INTERSECTION POINT OF TC & AMMEND SURWT TOTAL
 1440 Y=AMT*XWH0+CT
      X=XWH0
      IF(CTRLSU)1442,1442,1443
 1442 ALEN=SQRT((XSUR-X)**2+(YSUR-Y)**2)
      GO TO 1444
 1443 ALEN=SQRT((SX(I+1)-X)**2+(SY(I+1)-Y)**2)
 1444 SURWT=SURWT-(ALEN*SURCH(I))
      GO TO 1460

C     VERTICAL SURFACE ELEMENT
 1455 IF(SX(I).LE.WALLXX(NOBC))GO TO 1436
      IF(SY(I+1).GT.SY(I))GO TO 1457
      Y=AMB*SX(I)+CBOT
      D=SY(I)-Y
      IF(D.LT.H0)GO TO 1457
      X=SX(I)
      Y=SY(I)
      I=I-1
      GO TO 1460

C     MOVE BACK ONE ELEMENT
 1457 I=I-1
      GO TO 1410


 1460 XSUR=X
      YSUR=Y
      JEND=I

      RETURN
      END
```

```
C     SUBROUTINE DATACH : DATA CHANGE


      SUBROUTINE DATACH
      COMMON IDFILE(2000)
      COMMON/BLOCK4/QS,QWS,PYE,PYE2,PYE4
      COMMON/BLOCK5/QFRONT,ANGFRT
      COMMON/BLOCK8/CB,CA
      COMMON/BLOCKC/UP,WATER,PB2,PWATER
      COMMON/BLOCKE/PB1
      COMMON/BLOCKQ/H0,XSAVE,YSAVE,SX,SY,WATERB
      COMMON/GROUPG/CFOUND,QFS,QWFS,Q0,QNCMAX,XFRONT,YFRONT
      COMMON/GROUPK/GO,APPLE,NRATIO,RATIOS,BASELO,BASIC(25)
      COMMON/GROUPL/TSTEM,TBASE,HFRONT,DFSTIP,DFSLID,DFSBCY
      DIMENSION BASELO(10),RATIOS(10)
      LOGICAL LOG,LOGF,GO
      LOG=.TRUE.
      LOGF=.FALSE.
      CALL ERASE

C     (1) OUTPUT DATA LIST
      CALL SENDHS('      ***BASIC DATA CHANGE***')
      CALL SENDHS('.')
      CALL SENDHS('BACKFILL   : DRY DENSITY       :')
      CALL SENDHS('           : SUBMERGED DENSITY :')
      CALL SENDHS('           : SOIL FRICTION     :')
      CALL SENDHS('           : WALL FRICTION     :')
      CALL SENDHS('           : COHESION          :')
      CALL SENDHS('           : ADHESION          :')
      CALL SENDHS('           :WATER LEVEL        :')
      CALL SENDHS('FOUNDATION : BEARING CAPACITY  :')
      CALL SENDHS('           : BEARING MAXIMUM   :')
      CALL SENDHS('           : SOIL FRICTION     :')
      CALL SENDHS('           : BASE FRICTION     :')
      CALL SENDHS('           : COHESION          :')
      CALL SENDHS('AUTOMATIC  : STEM THICKNESS    :')
      CALL SENDHS('           : BASE THICKNESS    :')
      CALL SENDHS('           : RETAINED HEIGHT   :')
      CALL SENDHS('           : DESIGN FSTIP      :')
      CALL SENDHS('           : DESIGN FSLID      :')
      CALL SENDHS('           : DESIGN FSBCY      :')
      CALL SENDHS('FRONT SOIL : X-COORDINATE      :')
      CALL SENDHS('           : Y-COORDINATE      :')
      CALL SENDHS('           : ANGLE OF SLOPE    :')
      CALL SENDHS('           : % PASSIVE PRESSURE:')
      CALL SENDHS('.')
      CALL SENDHS('.')
      CALL SENDHS('.')
      CALL SENDHS('.')
      CALL SENDHS('AMENDMENTS COMPLETE')
      CALL MENUIN(LOGF,1)
      DO 88410 I=1,25
88410 CALL INSERT('.',1)

C     (2) SELECT ITEM TO AMEND
88420 CALL CURSOR(JC,ICX,ICY)
```

```
      KEY=IPOSN(ICY)
      IF(KEY.GT.24)GO TO 88430
      IY=747-KEY*22
      CALL MOVETO(650,IY,IDUM,0,1)
      CALL RLDISP(BASIC(KEY),8,2)
      CALL DEPICT(IDFILE,1)

C     (3) INSERT NEW VALUE
      CALL NOECHO
      CALL SENDRL(BASIC(KEY),0,0,LOG)
      CALL ECHO
      CALL MOVETO(800,IY,IDUM,0,1)
      CALL RLDISP(BASIC(KEY),8,2)
      CALL DEPICT(IDFILE,1)
      GO TO 88420

C     (4) RESET BASIC DATA ARRAY
88430 PB1=BASIC(1)
      PB2=BASIC(2)
      QS=BASIC(3)
      QWS=BASIC(4)
      CB=BASIC(5)
      CA=BASIC(6)
      WATERB=BASIC(7)
      Q0=BASIC(8)
      QNCMAX=BASIC(9)
      QFS=BASIC(10)
      QWFS=BASIC(11)
      CFOUND=BASIC(12)
      TSTEM=BASIC(13)
      TBASE=BASIC(14)
      HFRONT=BASIC(15)
      DFSTIP=BASIC(16)
      DFSLID=BASIC(17)
      DFSBCY=BASIC(18)
      XFRONT=BASIC(19)
      YFRONT=BASIC(20)
      ANGFRT=BASIC(21)
      QFRONT=BASIC(22)
      APPLE=BASIC(23)

      RETURN
      END
```

```
C      SUBROUTINE DATOUT : OUTPUT CO-ORDINATES AND BASIC DATA TERMS



      SUBROUTINE DATOUT
      COMMON IDFILE(2000)
      COMMON/BLOCK4/QS,QWS,PYE,PYE2,PYE4
      COMMON/BLOCK5/QFRONT,ANGFRT
      COMMON/BLOCK6/WX,WY,XWLFRT,YWLFRT
      COMMON/BLOCK8/CB,CA
      COMMON/BLOCKC/UP,WATER,PB2,PWATER
      COMMON/BLOCKE/PB1
      COMMON/BLOCKI/WALLXX,WALLYY,NOBC,NC,ISLOPE
      COMMON/BLOCKQ/H0,XSAVE,YSAVE,SX,SY,WATERB
      COMMON/BLOCKR/IA,TANS,DELTAW,WDASH,SURWT,SURCH,XSUR,YSUR,XWH0
      COMMON/BLOCKW/RERUN,NSC,XXXXIT,MANUAL,CRITTP,CRITSL,CRITBC,WWALL
      COMMON/GROUPG/CFOUND,QFS,QWFS,Q0,QNCMAX,XFRONT,YFRONT
      COMMON/GROUPL/TSTEM,TBASE,HFRONT,DFSTIP,DFSLID,DFSBCY
      DIMENSION WALLXX(4),WALLYY(4)
      DIMENSION WX(12),WY(12),SX(12),SY(12),SURCH(12)
      LOGICAL LOG,LOGF
      LOG=.TRUE.
      LOGF=.FALSE.

C      (1) OUTPUT WALL CO-ORDINATES
      CALL MOVETO(35,725,IDUM,0,1)
      CALL HOLSTR(' WALL COORDINATES')
      CALL MOVETO(35,721,IDUM,0,1)
      CALL LINE(235,0,LOG)
      CALL MOVETO(35,694,IDUM,0,1)
      CALL HOLSTR('  X          Y  ')
      DO 886 I=1,NC
      IY=680-I*20
      CALL MOVETO(25,IY,IDUM,0,1)
      CALL RLDISP(WX(I),6,2)
      CALL MOVETO(165,IY,IDUM,0,1)
  886 CALL RLDISP(WY(I),6,2)

C      (2) OUTPUT OF SURFACE COORDINATES
      CALL MOVETO (550,725,IDUM,0,1)
      CALL HOLSTR('GROUND COORDINATES')
      CALL MOVETO(550,721,IDUM,0,1)
      CALL LINE(245,0,LOG)
      CALL MOVETO(480,694,IDUM,0,1)
      CALL HOLSTR('     X        Y      SURCHARGE')
      DO 8857 I=1,NSC
      IY=680-I*20
      CALL MOVETO(475,IY,IDUM,0,1)
      CALL RLDISP(SX(TR),7,2)
      CALL MOVETO(580,IY,IDUM,0,1)
      CALL RLDISP(SY(I),7,2)
      IF(I.EQ.NSC)GO TO 8857
      CALL MOVETO(680,IY,IDUM,0,1)
      CALL RLDISP(SURCH(I),8,2)
 8857 CONTINUE
```

```
C      (3) OUTPUT SOIL PROPERTIES
       CALL MOVETO(35,410,IDUM,0,1)
       CALL HOLSTR('BACKFILL PROPERTIES')
       CALL MOVETO(35,406,IDUM,0,1)
       CALL LINE(257,0,LOG)
       CALL MOVETO(35,380,IDUM,0,1)
       CALL HOLSTR('ANGLE OF INTERNAL FRICTION :')
       CALL MOVETO(360,380,IDUM,0,1)
       CALL RLDISP(QS,12,2)
       CALL MOVETO(35,360,IDUM,0,1)
       CALL HOLSTR('ANGLE OF WALL FRICTION     :')
       CALL MOVETO(360,360,IDUM,0,1)
       CALL RLDISP(QWS,12,2)
       CALL MOVETO(35,340,IDUM,0,1)
       CALL HOLSTR('DRY DENSITY                : ')
       CALL MOVETO(360,340,IDUM,0,1)
       CALL RLDISP(PB1,12,2)
       CALL MOVETO(35,320,IDUM,0,1)
       CALL HOLSTR('SATURATED DENSITY          :')
       CALL MOVETO(360,320,IDUM,0,1)
       CALL RLDISP(PB2,12,2)
       CALL MOVETO(35,300,IDUM,0,1)
       CALL HOLSTR('COHESIVE STRENGTH          :')
       CALL MOVETO(360,300,IDUM,0,1)
       CALL RLDISP(CB,12,2)
       CALL MOVETO(35,280,0,1)
       CALL HOLSTR('ADHESIVE STRENGTH          :')
       CALL MOVETO(360,280,IDUM,0,1)
       CALL RLDISP(CA,12,2)
       CALL MOVETO(35,250,IDUM,0,1)
       CALL HOLSTR('FOUNDATION PROPERTIES')
       CALL MOVETO(35,246,IDUM,0,1)
       CALL LINE(270,0,LOG)
       CALL MOVETO(35,210,IDUM,0,1)
       CALL HOLSTR('ANGLE OF INTERNAL FRICTION :')
       CALL MOVETO(360,210,IDUM,0,1)
       CALL RLDISP(QFS,12,2)
       CALL MOVETO(35,190,IDUM,0,1)
       CALL HOLSTR('ANGLE OF WALL FRICTION     :')
       CALL MOVETO(360,190,IDUM,0,1)
       CALL RLDISP(QWFS,12,2)
       CALL MOVETO(35,170,IDUM,0,1)
       CALL HOLSTR('BASE ADHESION              :')
       CALL MOVETO(360,170,IDUM,0,1)
       CALL RLDISP(CFOUND,12,2)
       CALL MOVETO(35,150,IDUM,0,1)
       CALL HOLSTR('BEARING CAPACITY           :')
       CALL MOVETO(360,150,IDUM,0,1)
       CALL RLDISP(Q0,12,2)
       CALL MOVETO(35,130,IDUM,0,1)
       CALL HOLSTR('BEARING MAXIMUM             ')
       CALL MOVETO(360,130,IDUM,0,1)
       CALL RLDISP(QNCMAX,12,2)

C      (4) OUTPUT FRONT OF WALL CONDITIONS
```

```
CALL MOVETO(600,410,IDUM,0,1)
CALL HOLSTR('FRONT CONDITIONS')
CALL MOVETO(600,406,IDUM,0,1)
CALL LINE(235,0,LOG)
CALL MOVETO(600,380,IDUM,0,1)
CALL HOLSTR('X-COORD       :')
CALL MOVETO(781,380,IDUM,0,1)
CALL RLDISP(XFRONT,8,2)
CALL MOVETO(600,360,IDUM,0,1)
CALL HOLSTR('Y-COORD       :')
CALL MOVETO(781,360,IDUM,0,1)
CALL RLDISP(YFRONT,8,2)
CALL MOVETO(600,340,IDUM,0,1)
CALL HOLSTR('SLOPE         :')
CALL MOVETO(781,340,IDUM,0,1)
CALL RLDISP(ANGFRT,8,2)
CALL MOVETO(600,320,IDUM,0,1)
CALL HOLSTR('SURCHARGE     :')
CALL MOVETO(781,320,IDUM,0,1)
CALL RLDISP(QFRONT,8,2)

CALL ERASE
RETURN
END
```

```
C     SUBROUTINE FRICLE :PASSIVE PRESSURES BY FRICTION CIRCLE METHOD



      SUBROUTINE FRICLE
      COMMON/BLOCK1/AMMTY,AREA
      COMMON/BLOCK2/SIGNR,ANGR,ALR,XR,YR
      COMMON/BLOCK3/XT,YT,ANGF
      COMMON/BLOCK4/QS,QWS,PYE,PYE2,PYE4
      COMMON/BLOCK5/QFRONT,ANGFRT
      COMMON/BLOCK6/WX,WY,XWLFRT,YWLFRT
      COMMON/BLOCK7/XPASE,YPASE,APASE,PASIVE
      COMMON/BLOCK8/CB,CA
      COMMON/BLOCK9/SAVEPP,SAVPP1,SAVPP2
      COMMON/BLOCKE/PB1
      DIMENSION WX(12),WY(12)


C     (1) SET CONSTANTS FOR ANALYSIS
      XFRT=XWLFRT-WX(1)
      P=SIN(ANGFRT)/SIN(QS)
      P=0.5*(ASIN(P)-ANGFRT)
      A=PYE4-P-(QS/2.0)
      TANA=SIN(A)/COS(A)
      HWALL=YWLFRT-WY(1)
      TANFRT=SIN(ANGFRT)/COS(ANGFRT)
      AWALL=PYE2
      IF(XFRT.NE.0.0)AWALL=ATAN(HWALL/XFRT)
      TAWALL=SIN(AWALL)/COS(AWALL)
      COSFRT=COS(ANGFRT)
      CONST=SQRT(COSFRT**2-COS(QS)**2)
      AKP=COSFRT*(COSFRT+CONST)/(COSFRT-CONST)
      TAN2=PYE4-(QS/2.0)+P
      TAN2=SIN(TAN2)/COS(TAN2)
      E=PYE4+(QS/2.0)-ANGFRT+0.5*P
      E1=PYE4+(QS/2.0)-0.5*P
      SAVEPP=1000000.0
      ALEN=(XWLFRT-WX(1))**2+(YWLFRT-WY(1))**2
      ADHESN=CA*SQRT(ALEN)
      XD1=0.0
      DELXD1=0.10


C     (2) ESTABLISH LINE ON WHICH CIRCLE CENTRE LIES
 1898 XD1=XD1+DELXD1
      HD1=TANA*(XD1+XFRT)
      HD2=HD1+TANFRT*(XD1+XFRT)
      X1=WX(1)-XD1
      Y1=YWLFRT-HD1
      Y=(TAN2*TAWALL*(X1-WX(1))+TAWALL*Y1+TAN2*WY(1))/(TAWALL+TAN2)
      IF(Y.GT.WY(1))GO TO 1898
      SURL=HD2*SIN(E)/SIN(E1)
      XD2=SURL*COS(ANGFRT)
      YD2=SURL*SIN(ANGFRT)
      XS=X1-XD2
      YS=Y1+HD2+YD2
      Y1T=Y1+HD2
```

```
C      (3) ESTABLISH CENTRE OF FRICTION CIRCLE
       ANGLE=PYE4+P-(QS/2.0)
       C=WX(1)-X1
       D=WY(1)-Y1
       R1=(C**2+D**2)/(2.0*C*SIN(ANGLE)+2.0*D*COS(ANGLE))
       XC=X1+R1*SIN(ANGLE)
       YC=Y1+R1*COS(ANGLE)
       RC=R1*SIN(QS)
       ANGCHN=ATAN((WY(1)-Y1)/(WX(1)-X1))
       IF(CB.GT.0.0)GO TO 1899
       IF(QFRONT.GT.0.0)GO TO 18985
       P11=0.0
       GO TO 915


C      (4) STORE SURCHARGE DATA FOR COHESIONLESS SOIL
 18985 AL=XD1+XFRT
       ALR=AL*QFRONT/COS(ANGFRT)
       XR=XWLFRT-0.5*AL
       YR=YWLFRT+0.5*AL*TANFRT
       SIGNR=-1.0
       ANGR=PYE2
       GO TO 1910


C      CALCULATION OF PASSIVE FORCE ON FRONT OF WALL
C      (5) RESOLVE ADHESION AND COHESION FORCES
  1899 BLEN=SQRT((WX(1)-X1)**2+(Y1-WY(1))**2)
       COHESN=BLEN*CB
       XMP=X1+0.5*(WX(1)-X1)
       YMP=Y1+0.5*(WY(1)-Y1)
       T=(XC-XMP)/(YC-YMP)
       ANGCEN=ASIN(0.5*BLEN/R1)
       ANGCEN=2.0*ANGCEN
       RMP=R1*COS(0.5*ANGCEN)
       ARCBD1=R1*ANGCEN
       BLEN1=R1*ARCBD1/ALEN
       DELTAL=ALEN1-RMP
       ANGLE=ATAN((XC-XMP)/(YC-YMP))
       XCS1=XMP-DELTAL*SIN(ANGLE)
       YCS1=YMP-DELTAL*COS(ANGLE)
       CALL RESOLV(WX(1),WY(1),ADHESN,-1.0,AWALL,XCS1,
      1           YCS1,COHESN,1.0,ANGCHN)


C      (6) RESOLVE RESULTANT AND SURCHARGE FORCES
       AL=XD1+XFRT
       AL2=AL*QFRONT/COS(ANGFRT)
       X2=XWLFRT-0.5*AL
       Y2=YWLFRT+0.5*AL*TANFRT
       X3=XR
       Y3=YR
       AL3=ALR
       SIGN3=SIGNR
       ANG3=ANGR
       CALL RESOLV(X3,Y3,AL3,SIGN3,ANG3,X2,Y2,AL2,-1.0,PYE2)
```

```
C       (7) RESOLVE RESULTANT AND PD11
 1910 PD11=HD1*((2.0*CB*SQRT(AKP))+(QFRONT*AKP))
      ANGPD1=-ANGFRT
      Y2=Y1+0.5*HD2
      X3=XR
      Y3=YR
      SIGN3=SIGNR
      AL3=ALR
      ANG3=ANGR
      CALL RESOLV(X3,Y3,AL3,SIGN3,ANG3,X1,Y2,PD11,1.0,ANGPD1)


C       (8) FIND POINT OF INTERSECTION OF RESULTANT AND P11
      ANGP11=QWS+AWALL-PYE2
      YP11=HWALL/2.0+WY(1)
      XP11=WX(1)+0.5*(XFRT)
      ALRSAV=ALR
      ANGRSV=ANGR
      X3=XR
      Y3=YR
      ANG3=ANGR
      AL3=ALR
      SIGN3=SIGNR
      CALL RESOLV(X3,Y3,AL3,SIGN3,ANG3,XP11,YP11,10.0,-1.0,ANGP11)
      XF11=XR
      YF11=YR


C       (9) ESTABLISH LINE OF ACTION OF BASE RESULTANT AND HENCE
C             MAGNITUDE OF P11
      CALL TANGNT(XC,YC,XF11,YF11,RC)
      ANGF11=ANGF
      A1=ANGF11-ANGP11
      A2=PYE-ANGF11+ANGRSV
      P11=ALRSAV*SIN(A2)/SIN(A1)


C       (10) RESOLVE FORCES W1 AND PD12
  915 Y=YWLFRT+TANFRT*XFRT
      CALL COG(WX(1),Y,WY(1),XWLFRT,YWLFRT,YWLFRT)
      WAREA=AREA
      WMMT=AMMTY
      CALL COG(X1,Y1T,Y1,WX(1),Y,WY(1))
      WAREA=WAREA+AREA
      WMMT=WMMT+AMMTY
      ANG=ANGCEN/2.0
      AREA=ANG*R1**2-(R1*COS(ANG)*BLEN/2.0)
      WAREA=WAREA+AREA
      XTEMP=WX(1)-0.5*BLEN*COS(ANGCHN)
      FACTOR=1.0
      IF(XTEMP.LT.0.0)FACTOR=-1.0
      WMMT=WMMT+FACTOR*AREA*XTEMP
      XBAR=WMMT/WAREA
      W1=WAREA*PB1
      PD12=0.5*PB1*(HD2**2)*AKP
```

```
      Y2=Y1+HD2/3.0
      CALL RESOLV(XBAR,0.0,W1,-1.0,PYE2,X1,Y2,PD12,1.0,-ANGFRT)


C     (11) FIND POINT OF INTERSECTION OF RESULTANT AND P12
      XP12=WX(1)+(XFRT/3.0)
      YP12=WY(1)+HWALL/3.0
      ANGP12=AWALL+QWS-PYE2
      ALRSAV=ALR
      ANGRSV=ANGR
      X3=XR
      Y3=YR
      ANG3=ANGR
      AL3=ALR
      SIGN3=SIGNR
      CALL RESOLV(X3,Y3,AL3,SIGN3,ANG3,XP12,YP12,10.0,-1.0,ANGP12)
      XF12=XR
      YF12=YR


C     (12) ESTABLISH LINE OF RESULTANT F12 AND HENCE P12
      CALL TANGNT(XC,YC,XF12,YF12,RC)
      ANGF12=ANGF
      A1=PYE+ANGRSV-ANGF12
      A2=ANGF12-ANGP12
      P12=ALRSAV*SIN(A1)/SIN(A2)
      PPQ=P12+P11
      IF(PPQ.GT.SAVEPP)GO TO 920
      SAVEPP=PPQ
      SAVPP1=P11
      SAVPP2=P12
      GO TO 1898


C     (13) FIND POINT OF APPLICATION OF PASSIVE FORCE
  920 HBAR=((SAVPP1*HWALL/2.0)+(SAVPP2*HWALL/3.0))/(SAVPP1+SAVPP2)
      YPASE=HBAR+WY(1)
      XPASE=XWLFRT+(YPASE-YWLFRT)*XFRT/HWALL
      APASE=ANGP12
      PASIVE=SAVEPP
      RETURN
      END

.
.
```

```
C     SUBROUTINE GRAPH : GRAPH DRAWING ROUTINE



      SUBROUTINE GRAPH
      COMMON IDFILE(2000)
      COMMON/GROUPX/GRAPH1,IXO,IYO,XSCALE,YSCALE,IPTX,IPTY
      COMMON/GROUPY/NX,NY,FACTOR,INCRX,INCRY
      COMMON/GROUPZ/ICROSS,IVERT,IHORZ
      DIMENSION IPTX(10),IPTY(20),XSCALE(10),YSCALE(20)
      LOGICAL GRAPH1,LOG,LOGF
      LOG=.TRUE.
      LOGF=.FALSE.

C     GENERAL GRAPH DRAWING INSTRUCTIONS
C     (1) DRAW AXES
      CALL MOVETO(IXO,IYO,IDUM,0,1)
      IY=290.00*FACTOR
      CALL LINE(0,IY,LOG)
      CALL LINE(0,-IY,LOGF)
      IX=320.00*FACTOR
      CALL LINE(IX,0,LOG)
      CALL LINE(-IX,0,LOGF)
      CALL MOVETO(IXO,IYO,IDUM,0,1)


C     (2) SCALE VERTICAL AXIS
      DO 5010 I=1,NY
      IY=IYO+INCRY*I
      CALL MOVETO(IXO,IY,IDUM,0,1)
      CALL SUBPIC(IHORZ,1.,0)
      IX=IXO-60
      CALL MOVETO(IX,IY,IDUM,0,1)
 5010 CALL RLDISP(YSCALE(I),4,1)
      CALL MOVETO(IXO,IYO,IDUM,0,1)


C     (3) SCALE HORIZONTAL AXIS
      IB=2
      IF(GRAPH1)IB=1
      DO 5015 I=1,NX
      IX=IXO+I*INCRX
      CALL MOVETO(IX,IYO,IDUM,0,1)
      CALL SUBPIC(IVERT,1.,0)
      IX1=IX-16
      IY=IYO-27
      CALL MOVETO(IX1,IY,IDUM,0,1)
 5015 CALL RLDISP(XSCALE(I),3,IB)
      CALL MOVETO(50,IYO,IDUM,0,1)

C     (4) MARK POINTS ON GRAPH
      DO 5017 I=1,NX-1
      CALL MOVETO(IPTX(I),IPTY(I),IDUM,0,1)
      CALL SUBPIC(ICROSS,1.,0)
      IDX=IPTX(I+1)-IPTX(I)
```

```
C     SUBROUTINE KEYS : INTERACTIVE COMMANDS FOR INPUT OF BASE KEY


      SUBROUTINE KEYS
      COMMON/GROUPF/DEPKEY,WIDKEY,XWATB,YWATB
      CALL SENDHS('DEPTH OF KEY :')
      CALL KILLLF
      CALL SENDRL(DEPKEY,0,0,.TRUE.)
      CALL ERASE
      CALL SENDHS('WIDTH OF KEY :')
      CALL KILLLF
      CALL SENDRL(WIDKEY,0,0,.TRUE.)
      RETURN
      END
```

```
C     SUBROUTINE PAPA : ASCERTAIN POINT OF APPLICATION OF ACTIVE FORCES


      SUBROUTINE PAPA
      COMMON/BLOCK6/WX,WY,XWLFRT,YWLFRT
      COMMON/BLOCKF/XISLOP,YISLOP,WSAVEX,WSAVEY,XNC,YNC
      COMMON/BLOCKG/NLIM1,NLIM2,NLIM3,NLIM5
      COMMON/BLOCKH/PATOP,XPATOP,YPATOP,PABOT,XPABOT,YPABOT
      COMMON/BLOCKI/WALLXX,WALLYY,NOBC,NC,ISLOPE
      COMMON/BLOCKN/ANGTOP,ANGBOT,ANGBAS
      COMMON/BLOCKO/DELBOT,DELTOP,ACTIVE(12),BACK
      DIMENSION WALLXX(4),WALLYY(4),WX(12),WY(12)

C     (1) SET INITIAL TERMS
      ANLIM1=NLIM1
      NLIM4=NLIM2+3
      NLIM6=NLIM1+2
      IF(BACK)1906,1899,1899

C     (2) WALL BACK BROKEN : REARRANGE ACTIVE() ARRAY
 1899 DO 1900 J=1,NLIM1
      J2=NLIM2+3-J
      J1=J2-2
 1900 ACTIVE(J2)=ACTIVE(J1)
      ACTIVE(NLIM6)=0.0
      DO 1905 J=1,NLIM1
      J2=NLIM1+2-J
      J1=J2-1
 1905 ACTIVE(J2)=ACTIVE(J1)
      ACTIVE(1)=0.0
      TOTLEN=ANLIM1
      N=NLIM1
      PATOP=ACTIVE(NLIM5)
      GO TO 1909

C     (3) WALL BACK PLANE : REARRANGE ACTIVE() ARRAY
 1906 DO 1908 J=1,NLIM2
      I=NLIM2+2-J
 1908 ACTIVE(I)=ACTIVE(I-1)
      ACTIVE(1)=0.0
      PABOT=0.0
      XPABOT=0.0
      YPABOT=0.0
      TOTLEN=2.0*ANLIM1
      N=NLIM2
      PATOP=ACTIVE(NLIM2+1)

C     (4) ESTABLISH POINT OF APPLICATION OF FORCE ON TOP PART OF WALL
 1909 ELLEN=DELTOP/SIN(ANGTOP)
      TOTLEN=TOTLEN*ELLEN
      AMMT=0.0
```

```
      DO 1910 I=1,N
      AI=I
      ANNO=AI-0.5
      ARM=TOTLEN-ANNO*ELLEN
      DELTAF=ACTIVE(I+1)-ACTIVE(I)
 1910 AMMT=AMMT+DELTAF*ARM
      ARM=0.0
      IF(PATOP.GT.0.0)ARM=AMMT/PATOP
      XPATOP=WSAVEX-ARM*COS(ANGTOP)
      YPATOP=WSAVEY+ARM*SIN(ANGTOP)
      YPATOP=YPATOP-YNC
      IF(BACK)1920,1912,1912


C     (5) ESTABLISH POINT OF APPLICATION OF FORCE ON BOTTOM PART OF WALL
 1912 AMMT=0.0
      ELLEN=DELBOT/SIN(ANGBOT)
      TOTLEN=ANLIM1*ELLEN
      DO 1915 I=1,NLIM1
      J=NLIM5+I
      AI=I
      ANNO=AI-0.5
      ARM=TOTLEN-ANNO*ELLEN
      DELTAF=ACTIVE(J+1)-ACTIVE(J)
 1915 AMMT=AMMT+DELTAF*ARM
      NLIM7=NLIM4-1
      ARM=AMMT/ACTIVE(NLIM7)
      N=NC-1
      IF(BACK.EQ.0.0)N=N+1
      XPABOT=WX(N)-ARM*COS(ANGBOT)
      YPABOT=ARM*SIN(ANGBOT)+WY(N)-WY(NC)
      PABOT=ACTIVE(NLIM7)


 1920 RETURN
      END
```

```
C     SUBROUTINE RESOLV : CALCULATION OF RESULTANT OF TWO FORCES


      SUBROUTINE RESOLV(X1,Y1,AL1,SIGN1,ANG1,X2,Y2,AL2,SIGN2,ANG2)
      COMMON/BLOCK2/SIGNR,ANGR,ALR,XR,YR
      COMMON/BLOCK4/QS,QWS,PYE,PYE2,PYE4

C     (1) CALCULATE RESULTANT MAGNITUDE
      HORIZ=SIGN1*AL1*COS(ANG1)+AL2*SIGN2*COS(ANG2)
      VERT=SIGN1*AL1*SIN(ANG1)+AL2*SIGN2*SIN(ANG2)
      ALR=SQRT(HORIZ**2+VERT**2)

C     (2) ESTABLISH POINT OF INTERSECTION
      SLOPE1=SIN(ANG1)/COS(ANG1)
      SLOPE2=SIN(ANG2)/COS(ANG2)
      C1=Y1-SLOPE1*X1
      C2=Y2-SLOPE2*X2
      IF(ANG1.NE.PYE2)GO TO 10
      XR=X1
      YR=C2+SLOPE2*XR
      GO TO 30
   10 IF(ANG2.NE.PYE2)GO TO 20
      XR=X2
      YR=C1+SLOPE1*XR
      GO TO 30
   20 XR=(C2-C1)/(SLOPE1-SLOPE2)
      YR=(SLOPE1*XR)+C1

C     (3) ESTABLISH ANGLE AND SIGN OF RESULTANT
   30 ANGR=ATAN(VERT/HORIZ)
      SIGNR=HORIZ/(ABS(HORIZ))

      RETURN
      END
```

```
C     SUBROUTINE SCREEN : GRAPHICS INTERACTION AND OUTPUT



      SUBROUTINE BLAST
      COMMON IDFILE(2000)
      COMMON/BLOCKA/MINBAS(10)
      COMMON/BLOCK4/QS,QWS,PYE,PYE2,PYE4
      COMMON/BLOCK5/QFRONT,ANGFRT
      COMMON/BLOCK6/WX,WY,XWLFRT,YWLFRT
      COMMON/BLOCK8/CB,CA
      COMMON/BLOCKE/PB1
      COMMON/BLOCKH/PATOP,XPATOP,YPATOP,PABOT,XPABOT,YPABOT
      COMMON/BLOCKI/WALLXX,WALLYY,NOBC,NC,ISLOPE
      COMMON/BLOCKQ/H0,XSAVE,YSAVE,SX,SY,WATERB
      COMMON/BLOCKR/IA,TANS,DELTAW,WDASH,SURWT,SURCH,XSUR,YSUR,XWH0
      COMMON/BLOCKW/RERUN,NSC,XXXIT,MANUAL,CRITTP,CRITSL,CRITBC,WWALL
      COMMON/BLOCK7/XPASE,YPASE,APASE,PASIVE
      COMMON/BLOCKP/PWTOP,XPWTOP,YPWTOP,PWBAS,XPWBAS,YPWBAS
      COMMON/GROUPD/APATOP,APABOT,PABASE,APABAS,XPABAS,YPABAS
      COMMON/GROUPF/DEPKEY,WIDKEY,XWATB,YWATB
      COMMON/GROUPG/CFOUND,QFS,QWFS,Q0,QNCMAX,XFRONT,YFRONT
      COMMON/GROUPI/RESTP,RESSL,RESBC,RESBAS,RESWAL
      COMMON/GROUPJ/BASETD,TOE1,DELTOE,NTOED,QVMIN,QVMAX,DELTAB
      COMMON/GROUPK/GO,APPLE,NRATIO,RATIOS,BASELO,BASIC(25)
      COMMON/GROUPM/XBASE,YBASE
      COMMON/GROUPN/PWBOT,XPWBOT,YPWBOT,APWTOP,APWBOT,APWBAS
      COMMON/GROUPX/GRAPH1,IXO,IYO,XSCALE,YSCALE,IPTX,IPTY
      COMMON/GROUPY/NX,NY,FACTOR,INCRX,INCRY
      COMMON/GROUPZ/ICROSS,IVERT,IHORZ


      DIMENSION BASETD(10),BASELO(10),RESBAS(30),RESWAL(30)
      DIMENSION YSCALE(20),SURCH(12),WX(12),WY(12),SX(12),SY(12)
      DIMENSION XSCALE(10),ISX(12),ISY(12),IXWALL(12),IYWALL(12)
      DIMENSION IPTX(10),IPTY(20),WALLXX(4),WALLYY(4)
      DIMENSION RATIOS(10),RESSL(30),RESTP(30),RESBC(30)
      LOGICAL GRAPH1,DRAW,GO,RERUN,OVER,LOGF,XXXIT,MANUAL,LOG


C     *** SET LOGICAL VARIABLES TO INITIAL VALUES ***
      GO=.FALSE.
      RERUN=.FALSE.
      XXXIT=.FALSE.
      LOG=.TRUE.
      LOGF=.FALSE.
      GRAPH1=.FALSE.
      DRAW=.FALSE.


 5005 CALL DEFPIC(IDFILE,2000)



C     *** DEFINITION OF SUBPICTURES ***

C     SUBPICTURE TO DRAW LETTER R
      CALL DEFSUB(IRAR)
```

```
      CALL LINE(-5,0,LOGF)
      CALL LINE(10,0,LOG)
      CALL LINE(-5,0,LOGF)
      CALL LINE(0,80,LOG)
      CALL LINE(20,0,LOG)
      CALL LINE(10,-1,LOG)
      CALL LINE(8,-2,LOG)
      CALL LINE(6,-3,LOG)
      CALL LINE(4,-5,LOG)
      CALL LINE(2,-5,LOG)
      CALL LINE(0,-3,LOG)
      CALL LINE(-2,-5,LOG)
      CALL LINE(-4,-5,LOG)
      CALL LINE(-6,-3,LOG)
      CALL LINE(-8,-2,LOG)
      CALL LINE(-10,-1,LOG)
      CALL LINE(-20,0,LOG)
      CALL LINE(20,0,LOGF)
      CALL LINE(30,-45,LOG)
      CALL LINE(-5,0,LOGF)
      CALL LINE(10,0,LOG)
      CALL LINE(-55,0,LOGF)
      CALL ENDSUB(IRAR)

C     SUBPICTURE FOR UPWARD ARROW
      CALL DEFSUB(IMARK)
      CALL LINE(-6,-20,LOG)
      CALL LINE(12,0,LOG)
      CALL LINE(-6,20,LOG)
      CALL LINE(0,-40,LOGF)
      CALL LINE(0,40,LOG)
      CALL ENDSUB(IMARK)

C     SUBPICTURE TO DRAW CROSS
      CALL DEFSUB(ICROSS)
      CALL LINE(-5,-5,.FALSE.)
      CALL LINE(10,10,.TRUE.)
      CALL LINE(0,-10,.FALSE.)
      CALL LINE(-10,10,.TRUE.)
      CALL LINE(5,-5,.FALSE.)
      CALL ENDSUB(ICROSS)

C     SUBPICTURE TO DRAW ARROW
      CALL DEFSUB(IARROW)
      CALL LINE(-6,20,LOG)
      CALL LINE(6,0,LOG)
      CALL LINE(0,40,LOGF)
      CALL LINE(0,-40,LOG)
      CALL LINE(6,0,LOG)
      CALL LINE(-6,-20,LOG)
      CALL ENDSUB(IARROW)

C     SUBPICTURE TO DRAW DOT
      CALL DEFSUB(IDOT)
      CALL LINE(-1,-1,LOG)
      CALL LINE(0,2,LOG)
```

```
      CALL LINE(2,0,LOG)
      CALL LINE(0,-2,LOG)
      CALL LINE(-2,0,LOG)
      CALL LINE(1,1,LOGF)
      CALL ENDSUB(IDOT)

      IF(MANUAL)GO TO 849


C     ADDITIONAL SUBPICTURES REQUIRED FOR GRAPHS
C     SUBPICTURE FOR VERTICAL NODE POINT
      CALL DEFSUB(IVERT)
      CALL LINE(0,10,.TRUE.)
      CALL ENDSUB(IVERT)

C     SUBPICTURE FOR HORIZONTAL NODE POINT
      CALL DEFSUB(IHORZ)
      CALL LINE(10,0,.TRUE.)
      CALL ENDSUB(IHORZ)


C     *** AUTOMATIC ANALYSIS : USER INTERACTION ***

 5006 NX=NTOED
      CALL ERASE
      CALL SENDHS('**AUTOMATIC CANTILEVER ANALYSIS**')
      CALL SENDHS('.')
      CALL SENDHS('.')
      CALL SENDHS('GRAPH OF BASE AGAINST TOE DEPTH')
      CALL SENDHS('GRAPH OF BASE AGAINST RATIO')
      CALL SENDHS('TABLE OF RESULTS')
      CALL SENDHS('DRAWING OF SECTION')
      CALL SENDHS('BASE KEY')
      CALL SENDHS('RE-RUN PROGRAM')
      CALL SENDHS('RE-RUN AUTOMATIC ANALYSIS')
      CALL SENDHS('CHANGE TO MANUAL ANALYSIS')
      CALL SENDHS('BASIC DATA CHANGE')
      CALL SENDHS('EXIT')

      CALL MENUIN(LOGF,1)
      CALL INSERT('       .',8)
      CALL INSERT('       1',8)
      CALL INSERT('       2',8)
      CALL INSERT('       3',8)
      CALL INSERT('       4',8)
      CALL INSERT('       5',8)
      CALL INSERT('       6',8)
      CALL INSERT('       7',8)
      CALL INSERT('       8',8)
      CALL INSERT('       9',8)
      CALL INSERT('      10',8)
      CALL CURSOR(JC,ICX,ICY)
      KEY=IPOSN(ICY)
      CALL MENUMK(KEY)
```

```
      GO TO (5009,5009,5020,5030,849,8883,8901,8900,
     1       8825,8848,898),KEY


C     *** AUTOMATIC ANALYSIS : GRAPH OF BASE AGAINST TOE DEPTH ***

C     (1) SCALEX-AXIS AND FORM X-COORDINATES
 5009 CALL ERASE
      GRAPH1=.TRUE.
      CALL STRIP(1)
      INCRX=630/NTOED
      NX=NTOED
      AT=TOE1-DELTOE
      DO 5007 I=1,NTOED
      A=I
      XSCALE(I)=AT+(DELTOE*A)
 5007 IPTX(I)=100+I*INCRX

C     (2) SCALE Y-AXIS AND FORM Y-COORDINATES
      A=(OVMAX-OVMIN)/DELTAB
      NY=A+2.0
      INCRY=550/NY
      DO 5008 I=1,NTOED
      N=(BASELO(I)-OVMIN)/DELTAB
 5008 IPTY(I)=130+INCRY*(1+N)
      DO 50080 I=1,NY
      A=I-1
50080 YSCALE(I)=OVMIN+DELTAB*A

C     (3) SET OTHER VALUES REQUIRED BY GRAPH
      FACTOR=2.00
      IXO=100
      IYO=130

C     (4) LABEL GRAPH AND LIST RATIOS CONSIDERED
      CALL MOVETO(270,20,IDUM,0,1)
      CALL HOLSTR(' GRAPH OF BASE AGAINST TOE DEPTH')
      CALL MOVETO(300,721,IDUM,0,1)
      CALL MOVETO(750,750,IDUM,0,1)
      CALL HOLSTR('RATIOS CONSIDERED')
      CALL MOVETO(750,744,IDUM,0,1)
      CALL LINE(223,0,LOG)
      DO 50085 I=1,NRATIO
      IY=750-25*I
      CALL MOVETO(800,IY,IDUM,0,1)
      CALL RLDISP(RATIOS(I),6,3)
50085 CONTINUE
      CALL MOVETO(400,74,IDUM,0,1)
      CALL HOLSTR('TOE DEPTH')

C     (5) DRAW GRAPH AND OUTPUTDISPLAY FILE
      CALL GRAPH
      CALL BORDER
      CALL DEPICT(IDFILE,1)
```

```
      CALL CURSOR(IDUM,IDUMX,IDUMY)
      GO TO 5006


C     *** AUTOMATIC ANALYSIS : GRAPHS OF BASE AGAINST RATIO ***

C     (1) SELECT SCALE FACTOR FOR GRAPH
 5020 CALL ERASE
      IF(NRATIO.GT.1)GO TO 5021
      CALL SENDHS('ONLY ONE RATIO CONSIDERED : GRAPH CANNOT BE DRAWN')
      GO TO 5006
 5021 GRAPH1=.FALSE.
      CALL STRIP(1)
      FACTOR=1.0
      IF(NTOED.EQ.1)FACTOR=2.00


C     (2) SCALE X AND Y AXES
      DO 50200 I=1,NRATIO
50200 XSCALE(I)=RATIOS(I)
      NX=NRATIO
      INCRX=(300.00*FACTOR)/NX
      NY=1.0+(OVMAX-OVMIN)/DELTAB
      INCRY=(FACTOR*250.00)/NY
      DO 50210 I=1,NY
      A=I-1
50210 YSCALE(I)=OVMIN+DELTAB*A


C     (3) ESTABLISH X AND Y COORDINATES FOR GRAPH
      J=0
50220 J=J+1
      JG=J
      I1=1+NRATIO*(J-1)
      I2=J*NRATIO
      A=J-1
      TD=TOE1+A*DELTOE
      I=0


C     (4) CHECK VALUE OF JG NOT GREATER THAN 4
      IF(JG.LE.4)GO TO 50235
      JG=JG-4


C     (5) SELECT ORIGIN FOR GRAPH
50235 IXO=100
      IF(JG.EQ.2.OR.JG.EQ.4)IXO=600
      IYO=123
      IF(JG.EQ.3.OR.JG.EQ.4)IYO=476


C     (6) ESTABLISH X- AND Y-COORDS FOR GRAPH
      DO 50230 K=I1,I2
      I=I+1
      N=(RESBAS(K)-OVMIN)/DELTAB
50230 IPTY(I)=IYO+INCRY*(N+1)
      DO 50280 K=1,NRATIO
```

```
50280 IPTX(K)=IXO+K*INCRX

C     (7) TRANSFER GRAPH TO DISPLAY FILE
      CALL GRAPH

C     (8) MARK TOE DEPTH ON GRAPH
      I=FACTOR
      IY=IYO+(275*I)
      IX=IXO+60
      CALL MOVETO(IX,IY,IDUM,0,1)
      CALL HOLSTR('TOE DEPTH :')
      IX=IX+120
      CALL MOVETO(IX,IY,IDUM,0,1)
      CALL RLDISP(TD,7,2)
      IF(J.NE.NTOED.AND.JG.NE.4)GO TO 50220

C     (9) OUTPUT DISPLAY FILE
      CALL MOVETO(350,20,IDUM,0,1)
      CALL HOLSTR('GRAPH OF BASE AGAINST RATIO')
      CALL BORDER
      CALL DEPICT(IDFILE,1)

C     (10) CHECK TO SEE IF MORE GRAPHS REQUIRED
      CALL CURSOR(IDUM,IDUMX,IDUMY)
      CALL ERASE
      IF(J.LT.NTOED)GO TO 50220
      GO TO 5006


C     *** AUTOMATIC ANALYSIS : TABLE OF RESULTS ***

 5030 CALL ERASE
      CALL BORDER
      CALL MOVETO(270,20,IDUM,0,1)
      CALL HOLSTR('AUTOMATIC ANALYSIS : TABLE OF RESULTS')
      CALL MOVETO(165,739,IDUM,0,1)
      CALL LINE(125,0,LOG)
      CALL MOVETO(362,739,IDUM,0,1)
      CALL LINE(67,0,LOG)
      CALL MOVETO(543,739,IDUM,0,1)
      CALL LINE(53,0,LOG)
      CALL MOVETO(710,739,IDUM,0,1)
      CALL LINE(150,0,LOG)
      CALL DEPICT(IDFILE,1)
      CALL SENDHS('.')
      CALL SENDHS('TOE DEPTH     RATIO          BASE          WALL WEIGHT')
      CALL SENDHS('.')
      A=TOE1-DELTOE
      DO 5037 I=1,NX
      A=A+DELTOE
      DO 5037 J=1,NRATIO
      IJ=J+NRATIO*(I-1)
      CALL SENDRL(A,6,2,LOGF)
      CALL KILLLF
```

```
      CALL SENDRL(RATIOS(J),13,2,LOGF)
      CALL KILLLF
      CALL SENDRL(RESBAS(IJ),12,2,LOGF)
      CALL KILLLF
      CALL SENDRL(RESWAL(IJ),16,2,LOGF)
 5037 CONTINUE
      CALL CURSOR(IDUM,IXDUM,IYDUM)
      GO TO 5006


C     *** DRAW WALL SECTION AND GROUND PROFILE ***

C     FIX SCALE FOR DRAWING
  849 SLOPEF=SIN(ANGFRT)/COS(ANGFRT)
      CFRONT=YWLFRT-SLOPEF*XWLFRT
  850 OVER=.FALSE.
      WSCALE=400/(WY(ISLOPE)-WY(1))


C     FORM ARRRAYS FOR DRAWING CROSS SECTION
      IXWALL(1)=200
      IYWALL(1)=150
      NC1=NC-1
      DO 855 I=1,NC1
      DELTAX=(WX(I+1)-WX(I))*WSCALE
      IX=DELTAX
      IXWALL(I+1)=IXWALL(I)+IX
      DELTAY=(WY(I+1)-WY(I))*WSCALE
      IY=DELTAY
  855 IYWALL(I+1)=IYWALL(I)+IY


C     DRAW CROSS SECTION
      ISTART=INSTAT(200,150,ICROSS,1)
      CALL MSSLP(ISTART)
      DO 860 I=1,NC1
      J=I+1
      IX=IXWALL(J)-IXWALL(I)
      IY=IYWALL(J)-IYWALL(I)
      IG=NEWSEG(-1)
      CALL MOVETO(IXWALL(I),IYWALL(I),IDUM,0,1)
      CALL LINE(IX,IY,LOG)
      IPOINT=INSTAT(IXWALL(J),IYWALL(J),ICROSS,J)
      CALL MSSLP(IPOINT)
  860 CONTINUE
      IX=IXWALL(1)-IXWALL(NC)
      IY=IYWALL(1)-IYWALL(NC)


C     DRAW KEY IF PRESENT
      IF(DEPKEY.EQ.0.0)GO TO 8611
      IY=DEPKEY*WSCALE
      IX=WIDKEY*WSCALE
      CALL MOVETO(IXWALL(NC),IYWALL(NC),IDUM,0,1)
      CALL LINE(0,-IY,LOG)
      CALL LINE(-IX,0,LOG)
      IF(SSSSS.EQ.0.0)GO TO 8612
      IDELTA=WSCALE*WIDKEY*SIN(SSSSS)/COS(SSSSS)
```

```
      IY=IY+IDELTA
 8612 CALL LINE(0,IY,LOG)
      IX=IXWALL(1)-IXWALL(NC)+IX
      IY=IYWALL(1)-IYWALL(NC)-IDELTA
      IG=NEWSEG(-1)
 8611 CALL LINE(IX,IY,LOG)

C     FORM ARRAYS FOR DRAWING GROUND PROFILE
      ISX(1)=IXWALL(ISLOPE)
      ISY(1)=IYWALL(ISLOPE)
      NSC1=NSC-1
      DO 861 I=1,NSC1
      DELTAX=(SX(I+1)-SX(I))*WSCALE
      IX=DELTAX
      ISX(I+1)=ISX(I)+IX
      DELTAY=(SY(I+1)-SY(I))*WSCALE
      IY=DELTAY
  861 ISY(I+1)=ISY(I)+IY

C     DRAW OUT SURFACE OF BACKFILL
      ITOTX=IXWALL(ISLOPE)
      ITOTY=IYWALL(ISLOPE)
      NOSUR=101
      CALL MOVETO(200,150,IDUM,0,1)
      I=0
  865 I=I+1
      J=I+1
      NOSUR=NOSUR+1
      IX=ISX(J)-ISX(I)
      IY=ISY(J)-ISY(I)
      ITOTX=ITOTX+IX
      ITOTY=ITOTY+IY
  870 IF(ITOTX.GT.1020)GO TO 875
      IF(ITOTY.GT.780)GO TO 876
      IG=NEWSEG(-1)
      CALL MOVETO(ISX(I),ISY(I),IDUM,0,1)
      CALL LINE(IX,IY,LOG)
      IDOTT=INSTAT(ISX(I),ISY(I),IDOT,NOSUR)
      CALL MSSLP(IDOTT)
      IF(SURCH(I).EQ.0.0)GO TO 873
      IF(IX.EQ.0.AND.IY.EQ.0)GO TO 871

C     MAKE PROVISION FOR DISPLAY OF SURCHARGES
  872 ANGLE=ATAN((SY(I+1)-SY(I))/(SX(I+1)-SX(I)))
      X=-10.00*SIN(ANGLE)
      Y=10.00*COS(ANGLE)
      IDX=X
      IDY=Y
      CALL MOVETO(ISX(I),ISY(I),IDUM,0,1)
      CALL LINE(IDX,IDY,LOG)
      CALL LINE(IX,IY,LOG)
      CALL LINE(-IDX,-IDY,LOG)
      IX=ISX(I)+(IX/2)-50+3*IDX
      IY=ISY(I)+(IY/2)+IDY
      IS=SURCH(I)
      CALL MOVETO(IX,IY,IDUM,0,1)
      CALL INDISP(IS,5)
```

```
      CALL MOVETO(ISX(I+1),ISY(I+1),IDUM,0,1)
      GO TO 873

C     DISPLAY OF LINE LOAD
  871 CALL SUBPIC(IARROW,1.,0)
      IX=ISX(I)-20
      IY=ISY(I)+50
      CALL MOVETO(IX,IY,IDUM,0,1)
      IS=SURCH(I)
      CALL INDISP(IS,5)
      CALL MOVETO(ISX(I+1),ISY(I+1),IDUM,0,1)
  873 IF(OVER)GO TO 880
      IF(I.EQ.NSC-1)GO TO 880
      GO TO 865

C     EDGE VIOLATION ADJUSTMENT
C     (1) X ADJUSTMENT
  875 ITOTX=ITOTX-IX
      ITOTY=ITOTY-IY
      IAX=1020-ITOTX
      IY=(IY*IAX)/IX
      IX=IAX
      OVER=.TRUE.
      GO TO 870
C     (2) Y ADJUSTMENT
  876 ITOTX=ITOTX-IX
      ITOTY=ITOTY-IY
      IAY=770-IYTOT
      IX=(IX*IAY)/IY
      IY=IAY
      OVER=.TRUE.
      GO TO 870

C     DISPLAY OF GROUND IN FRONT OF WALL
  880 X=200.0+(XWLFRT-WX(1))*WSCALE
      Y=150.0+(YWLFRT-WY(1))*WSCALE
      IFX=X
      IFY=Y
      Y0=Y+SIN(ANGFRT)*(10.0-X)/COS(ANGFRT)
      CALL MOVETO(IFX,IFY,IDUM,0,1)
      DELTAX=10.0-X
      DELTAY=Y0-Y
      IX=DELTAX
      IY=DELTAY
      CALL LINE(IX,IY,LOG)
      IF(QFRONT.EQ.0.0)GO TO 881

C     DISPLAY OF SURCHARGE IN FRONT OF WALL
      X=10.00*SIN(ANGFRT)
      Y=10.00*COS(ANGFRT)
      IDX=X
      IDY=Y
      CALL MOVETO(IFX,IFY,IDUM,0,1)
      CALL LINE(IDX,IDY,LOG)
      CALL LINE(IX,IY,LOG)
      CALL LINE(-IDX,-IDY,LOG)
```

```
C     DISPLAY OF WATER LEVEL BEIND WALL
  881 IF(WATERB.LT.WY(NC))GO TO 8820
      X=200.0+WSCALE*(XWATB-WX(1))
      Y=150.0+WSCALE*(YWATB-WY(1))
      IX=X
      IY=Y
      CALL MOVETO(IX,IY,IDUM,0,1)
      N=(700-IX)/20
      DO 882 I=1,N
      CALL LINE(10,0,LOG)
  882 CALL LINE(10,0,LOGF)

C     MARK POSITION OF BASE RESULTANT
 8820 IX=(XBASE-WX(1))*WSCALE
      IY=(WY(1)-YBASE)*WSCALE
      IX=IXWALL(1)+IX
      IY=IYWALL(1)-IY
      CALL MOVETO(IX,IY,IDUM,0,1)
      CALL SUBPIC(IMARK,1.,0)

C     DISPLAY FACTORS OF SAFETY AND SELF WEIGHT
      IF(.NOT.MANUAL)GO TO 8823
      IG=NEWSEG(50)
      CALL MOVETO(700,370,IDUM,0,1)
      CALL HOLSTR(' FACTORS OF SAFETY')
      CALL MOVETO(700,340,IDUM,0,1)
      CALL HOLSTR(' TIPPING :')
      CALL RLDISP(CRITTP,7,2)
      CALL MOVETO(700,310,IDUM,0,1)
      CALL HOLSTR(' SLIDING :')
      CALL RLDISP(CRITSL,7,2)
      CALL MOVETO(700,280,IDUM,0,1)
      CALL HOLSTR(' BEARING :')
      CALL RLDISP(CRITBC,7,2)
      CALL MOVETO(700,220,IDUM,0,1)
      CALL HOLSTR(' WALL WEIGHT :')
      CALL RLDISP(WWALL,8,0)

C     CHECK FOR RE-DRAW
      IF(.NOT.DRAW)GO TO 8823
      CALL MOVETO(950,280,IDUM,0,1)
      CALL SUBPIC(IRAR,1.,0)

C     COMPILE AND DEPICT DISPLAY FILE
 8823 CALL ERASE
      CALL BORDER
      CALL DEPICT(IDFILE,1)
      GO TO 883
```

```
C      *** MANUAL ANALYSIS : USER INTERACTION ***

 8825 MANUAL=.TRUE.
  883 CALL CURSOR(JC,ICX,ICY)
      IF(JC.EQ."113)GO TO 8883
      IF(JC.EQ."102)GO TO 8884
      IF(MANUAL.EQ.LOGF)GO TO 5006
      IF(JC.EQ."114)GO TO 8870
      IF(JC.EQ."122)GO TO 8900
      IF(JC.EQ."103)GO TO 8848
      IF(JC.EQ."101)GO TO 899
      IF(JC.EQ."130)GO TO 898
      IF(JC.EQ."127)GO TO 885
      IF(JC.EQ."106)GO TO 8835
      IF(JC.EQ."110)GO TO 8880
      IF(JC.EQ."104)DRAW=.TRUE.
      IF(JC.EQ."104)GO TO 8885
      IF(JC.EQ."107)GO TO 8901
      CALL SFIND(ICX,ICY,ISN)
      IF(ISN.EQ.0)GO TO 883
      INEW=IUFIND(ISN)
      I=INEW-101
      IF(JC.EQ."120)GO TO 8831
      IF(JC.EQ."123)GO TO 8832
      IF(JC.NE."117)GO TO 8849


C      *** CONTROLLED CHANGE OF ORDINATE ***

      IF(INEW.LT.100)GO TO 8830
C      (1) SURFACE ORDINATE CHANGE
      INEW=INEW-101
      CALL SENDHS('SURFACE ORDINATE CHANGE : ')
      CALL SENDRL(SX(INEW),6,2,LOG)
      CALL SENDRL(SY(INEW),6,2,LOG)
      GO TO 883

C      (2) WALL ORDINATE CHANGE
 8830 CALL SENDHS('WALL ORDINATE CHANGE : ')
      CALL SENDRL(WX(INEW),6,2,LOG)
      CALL SENDRL(WY(INEW),6,2,LOG)
      IF(INEW.NE.ISLOPE)GO TO 883
      SX(1)=WX(ISLOPE)
      SY(1)=WY(ISLOPE)
      GO TO 883


C      *** CHANGE OF SURCHARGE LOADING ***

 8831 IF(SX(I+1).EQ.SX(I).AND.SY(I+1).EQ.SY(I))GO TO 8833
      I=I-1
      GO TO 8833
 8832 IF(INEW.LT.100)I=1
      IF(SX(I).EQ.SX(I+1).AND.SY(I).EQ.SY(I+1))I=I+1
 8833 CALL SENDHS('SURCHARGE CHANGE : ')
```

```
      CALL SENDRL(SURCH(I),8,2,LOG)
      GO TO 883




C     *** OUTPUT FORCE DATA ***
 8835 CALL ERASE
      TYPE 8549
 8549 FORMAT('.'//////)
      TYPE 8550
 8550 FORMAT('                  FORCE                MAGNITUDE     ANGLE
     1           X          Y'//)
      Y=YPATOP+WY(1)
      TYPE 8551,PATOP,APATOP,XPATOP,Y
 8551 FORMAT('                  ACTIVE TOP    ',F13.0,F10.2,F11.2,F9.2)
      Y=YPABOT+WY(1)
      TYPE 8552,PABOT,APABOT,XPABOT,Y
 8552 FORMAT('                  ACTIVE BOTTOM',F13.0,F10.2,F11.2,F9.2)
      Y=YPABAS+WY(1)
      TYPE 8553,PABASE,APABAS,XPABAS,Y
 8553 FORMAT('                  ACTIVE BASE   ',F12.0,F10.2,F11.2,F9.2/)
      TYPE 8554,PASIVE,APASE,XPASE,YPASE
 8554 FORMAT('                  PASSIVE       ',F11.0,F10.2,F11.2,F9.2/)
      Y=YPWTOP+WY(1)
      TYPE 8895,PWTOP,APWTOP,XPWTOP,Y
 8895 FORMAT('                  WATER TOP     ',F11.0,F10.2,F11.2,F9.2)
      Y=YPWBOT+WY(1)
      TYPE 8896,PWBOT,APWBOT,XPWBOT,Y
 8896 FORMAT('                  WATER BOTTOM  ',F11.0,F10.2,F11.2,F9.2)
      Y=WY(1)+YPWBAS
      TYPE 8887,PWBAS,APWBAS,XPWBAS,Y
 8887 FORMAT('                  WATER BASE    ',F11.0,F10.2,F11.2,F9.2)
      CALL MOVETO(120,611,IDUM,0,1)
      CALL LINE(70,0,.TRUE.)
      CALL MOVETO(365,611,IDUM,0,1)
      CALL LINE(120,0,.TRUE.)
      CALL MOVETO(563,611,IDUM,0,1)
      CALL LINE(65,0,.TRUE.)
      CALL MOVETO(742,611,IDUM,0,1)
      CALL LINE(16,0,.TRUE.)
      CALL MOVETO(864,611,IDUM,0,1)
      CALL LINE(16,0,.TRUE.)
      CALL MOVETO(430,20,IDUM,0,1)
      CALL HOLSTR('FORCE DETAILS')
      CALL BORDER
      CALL DEPICT(IDFILE,1)
      GO TO 883




C     *** DATA CHANGE ***
 8848 CALL ERASE
C     (1) OUTPUTDATA LIST
      CALL DATACH
C     AMENDMENTS COMPLETE
```

```
      IF(MANUAL)GO TO 883
      GO TO 5006


C     *** MOVE COORDINATE WITH CROSS-HAIRS ***

 8849 IF(INEW.GT.100)GO TO 8855
C     (1) WALL COORDINATE CHANGE
      CALL CURSOR(JC,ICX,ICY)
      IX=ICX-IXWALL(INEW)
      IY=ICY-IYWALL(INEW)
      DELTAX=IX
      DELTAY=IY
      WX(INEW)=WX(INEW)+DELTAX/WSCALE
      WY(INEW)=WY(INEW)+DELTAY/WSCALE
      IF(INEW.NE.ISLOPE)GO TO 8850
      SX(1)=WX(ISLOPE)
      SY(1)=WY(ISLOPE)
 8850 CALL SPDROP(ICX,ICY,IDOT,2.0,0)
      CALL MOVETO(ICX,ICY,IDUM,0,1)
      GO TO 883
C     (2) SURFACE COORDINATE CHANGE
 8855 INEW=INEW-101
      I=INEW
      IF(SX(I).EQ.SX(I+1).AND.SY(I).EQ.SY(I+1))INEW=INEW+1
      CALL CURSOR(JC,ICX,ICY)
      IX=ICX-ISX(INEW)
      IY=ICY-ISY(INEW)
      DELTAX=IX
      DELTAY=IY
      SX(INEW)=SX(INEW)+DELTAX/WSCALE
      SY(INEW)=SY(INEW)+DELTAY/WSCALE
      CALL SPDROP(ICX,ICY,IDOT,2.0,0)
      CALL MOVETO(ICX,ICY,IDUM,0,1)
      GO TO 883


C     *** OUTPUT COORDINATES AND SOIL PROPERTIES ***
  885 CALL ERASE
      CALL DATOUT
      CALL BORDER
      CALL MOVETO(430,20,IDUM,0,1)
      CALL HOLSTR('WALL SECTION')
      CALL DEPICT(IDFILE,1)
      GO TO 883


C     *** PROVIDE TEMPORARY CHANGE TO ALPHANUMERIC MODE ***
 8870 CALL NOECHO
      CALL SENDIN(IDUM,0,LOG)
      CALL ECHO
      IF(MANUAL)GO TO 883
      GO TO 5006
```

```
C      *** PROVISION OF USER ASSISTANCE ***
 8880 CALL ERASE
      CALL SENDHS('.')
      CALL SENDHS('.')
      CALL SENDHS('**USER CONTROL COMMANDS**')
      CALL SENDHS('.')
      CALL SENDHS('A : ANALYSE SECTION')
      CALL SENDHS('B : BORDER FOR DISPLAY')
      CALL SENDHS('C : CHANGE DATA')
      CALL SENDHS('D : DRAW SECTION')
      CALL SENDHS('E : ERASE CROSS-HAIRS TEMPORARILY')
      CALL SENDHS('F : FORCE DETAILS')
      CALL SENDHS('G : GO TO START OF ANALYSIS')
      CALL SENDHS('H : HELP - LIST OF USER COMMANDS')
      CALL SENDHS('K : KEY FOR BASE')
      CALL SENDHS('L : LINE LOAD ADJUSTMENT')
      CALL SENDHS('M : MOVE ANOTHER POINT NO REDRAW')
      CALL SENDHS('O : COORDINATE CHANGE VIA KEYBOARD')
      CALL SENDHS('R : RE-RUN PROGRAM')
      CALL SENDHS('S : SURCHARGE CHANGE')
      CALL SENDHS('W : WRITE OUT WALL COORDINATES')
      CALL SENDHS('X : EXIT FROM PROGRAM')
      GO TO 883


C      *** PROVIDE BASE KEY ***
 8883 CALL KEYS
      DRAW=.TRUE.
      IF(MANUAL)GO TO 8885
      GO TO 5006


C      *** PROVIDE BOUNDARY FOR DISPLAY ***
 8884 CALL BORDER
      CALL DEPICT(IDFILE,1)
      GO TO 883


C      *** REDRAW CHECKS ***

C       (1) CHECK INTERSECTION OF WATER AND WALL BACK
 8885 IF(WATERB.EQ.0.0)GO TO 888
      I=ISLOPE-1
 8886 I=I+1
      IF(WATERB.LT.WY(I+1))GO TO 8886
      IF(WATERB.EQ.WY(I+1))I=I+1
      XWATB=WX(I)
      YWATB=WATERB
      IF(WY(I+1).EQ.WY(I))GO TO 888
      XWATB=WX(I)+(WATERB-WY(I))*(WX(I+1)-WX(I))/(WY(I+1)-WY(I))
```

```
C      (2) CHECK POSITION OF GROUND INFRONT OF WALL
  888 I=0
  890 I=I+1
      IF(WY(I+1).EQ.WY(I))GO TO 890
      IF(WX(I).NE.WX(I+1))GO TO 895
      XWLFRT=WX(I)
      YWLFRT=SLOPEF*WX(I)+CFRONT
      GO TO 896
  895 T=(WY(I+1)-WY(I))/(WX(I+1)-WX(I))
      CWALL=WY(I)-WX(I)*T
      YWLFRT=(T*CFRONT-SLOPEF*CWALL)/(T-SLOPEF)
      XWLFRT=(YWLFRT-CWALL)/T
  896 IF(YWLFRT.GT.WY(I+1))GO TO 890


C      (3) REDRAW
  897 CALL STRIP(1)
      CALL ERASE
      GO TO 5005



C      *** SET LOGICAL TERMS ***
  898 XXXIT=.TRUE.
 8900 RERUN=.TRUE.
 8901 GO=LOG


C      *** CHECK ON X-COORDINATES OF WALL ***
  899 DO 900 I=1,NC-1
  900 IF((WX(I+1)-WX(I)).LT.0.0)WX(I+1)=WX(I)



      RETURN
      END
```

```
C     SUBROUTINE STRIPS : DIVISION OF WEDGE INTO VERTICAL STRIPS



      SUBROUTINE STRIPS
      COMMON/BLOCKB/XTOP,YTOP,YBOT,XBOT,NTOP,NBOT
      COMMON/BLOCKC/WATER,PB2,PWATER
      COMMON/BLOCKV/INO,JNO,TCSURW
      DIMENSION XTOP(15),YTOP(15),YBOT(15),XBOT(15)
      DIMENSION XTOP1(15),YTOP1(15),YBOT1(15)

C     ARRANGE ALL X-COORDS DEFINING TOP AND BOTTOM SURFACES
C     IN SEQUENCE INTO XTOP() ARRAY
      XTOP1(1)=XTOP(1)
      K=1
      I=2
      J=2
  260 K=K+1
  262 DELTA=XTOP(J)-XBOT(I)
      IF(DELTA.LT.0.001.AND.DELTA.GT.-0.01)GO TO 270
      IF(DELTA.GT.0.0)GO TO 275
      XTOP1(K)=XTOP(J)
      J=J+1
      GO TO 260
  270 IF(I.EQ.NBOT.AND.J.EQ.NTOP)GO TO 278
      XTOP1(K)=XTOP(J)
      IF(J.EQ.NTOP)GO TO 272
      J=J+1
  272 IF(I.EQ.NBOT)GO TO 260
      I=I+1
      GO TO 260
  275 IF(I.GT.2)GO TO 276
      IF(XBOT(I).EQ.XBOT(I-1))GO TO 277
  276 XTOP1(K)=XBOT(I)
      K=K+1
  277 I=I+1
      GO TO 262
  278 IF(XTOP1(K-1).EQ.XTOP(J))GO TO 280
      XTOP1(K)=XTOP(J)
      K=K+1
  280 KNO=K-1

C     FOR EACH VALUE OF XTOP1() CALCULATE YTOP1()
      K=1
      J=1
  285 IF(XTOP1(K).NE.XTOP(J+1))GO TO 287
      YTOP1(K)=YTOP(J+1)
      J=J+1
      GO TO 290
  287 SLOPES=(YTOP(J+1)-YTOP(J))/(XTOP(J+1)-XTOP(J))
      CSURF=YTOP(J)-XTOP(J)*SLOPES
      YTOP1(K)=SLOPES*XTOP1(K)+CSURF
  290 K=K+1
      IF(K.LE.KNO)GO TO 285
```

```
C     FOR EACH VALUE OF XTOP1() CALCULATE YBOT1()
      K=1
      J=1
  295 IF(XTOP1(K).NE.XBOT(J+1))GO TO 297
      YBOT1(K)=YBOT(J+1)
      J=J+1
      GO TO 298
  297 IF(XBOT(J).EQ.XBOT(J+1))GO TO 296
      SLOPEB=(YBOT(J+1)-YBOT(J))/(XBOT(J+1)-XBOT(J))
      CBACK=YBOT(J)-XBOT(J)*SLOPEB
      YBOT1(K)=SLOPEB*XTOP1(K)+CBACK
      GO TO 298
  296 YBOT1(K)=YBOT(J)
  298 K=K+1
      IF(K.LE.KNO)GO TO 295

C     TRANSFER STRIP COORDINATES TO XTOP(),YTOP() AND YBOT() ARRAYS
      DO 299 K=1,KNO
      XTOP(K)=XTOP1(K)
      YTOP(K)=YTOP1(K)
  299 YBOT(K)=YBOT1(K)
      NBOT=KNO
      NTOP=KNO

      RETURN
      END
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C     SUBROUTINE TANGNT : ESTABLISH LINE OF ACTION OF RESULTANT FORCE
C                         ON WEDGE BASE IN FRICTION CIRCLE ANALYSIS



      SUBROUTINE TANGNT(XCENTR,YCENTR,XRES,YRES,RADIUS)
      COMMON/BLOCK3/XT,YT,ANGF
      COMMON/BLOCK4/QS,QWS,PYE,PYE2,PYE4
      GP1=XCENTR-XRES
      GP2=YCENTR-YRES
      GP3=XCENTR*GP1+YCENTR*GP2-RADIUS**2
      GP4=GP3/GP2
      GP5=GP1/GP2
      GP6=1.00+GP5**2
      GP7=2.0*GP5*(YCENTR-GP4)-2.0*XCENTR
      GP8=XCENTR**2+YCENTR**2+GP4**2-RADIUS**2-2.0*YCENTR*GP4
      GP9=SQRT(GP7**2-4.0*GP6*GP8)
      X1=(-GP7+GP9)/(2.0*GP6)
      X2=(-GP7-GP9)/(2.0*GP6)
      IF(X2.GE.X1)X1=X2
      GP10=YCENTR**2+(X1-XCENTR)**2-RADIUS**2
      YT=YCENTR-SQRT(YCENTR**2-GP10)
      XT=X1
      ANGF=ATAN((YT-YRES)/(XT-XRES))
      RETURN
      END
```

```
C      SUBROUTINE TIGER : ESTABLISH POSITION OF TENSION CRACK BEHIND WALL


       SUBROUTINE TIGER
       COMMON/BLOCK1/AMMTY,AREA
       COMMON/BLOCK6/WX,WY,XWLFRT,YWLFRT
       COMMON/BLOCKB/XTOP,YTOP,YBOT,XBOT,NTOP,NBOT
       COMMON/BLOCKC/UP,WATER,PB2,PWATER
       COMMON/BLOCKD/SUMWT,SUMMTY
       COMMON/BLOCKE/PB1
       COMMON/BLOCKI/WALLXX,WALLYY,NOBC,NC,ISLOPE
       COMMON/BLOCKQ/H0,XSAVE,YSAVE,SX,SY,WATERB
       COMMON/BLOCKR/IA,TANS,DELTAW,WDASH,SURWT,SURCH,XSUR,YSUR
       COMMON/BLOCKV/INO,JNO,TCSURW
       COMMON/BLOCKU/JSTART,JEND,ZH0,ZS,XH0
       DIMENSION WX(12),WY(12),XTO(15),YTOP(15),YBOT(15)
       DIMENSION WALLXX(4),WALLYY(4),SX(12),SY(12),XBOT(15),SURCH(12)

       J=1
       I=ISLOPE
   200 IF(WX(I).EQ.WX(I+1))GO TO 210

C      WALL BACK NOT VERTICAL
       SLOPEB=(WY(I+1)-WY(I))/(WX(I+1)-WX(I))
       CBACK=WY(I+1)-SLOPEB*WX(I+1)
       IF(SX(J).EQ.SX(J+1))GO TO 235

C      SURFACE ELEMENT NOT VERTICAL
       SLOPES=(SY(J+1)-SY(J))/(SX(J+1)-SX(J))
       CSURF=SY(J)-SLOPES*SX(J)
       XH0=(H0-(CSURF-CBACK))/(SLOPES-SLOPEB)
       IF(XH0.LT.SX(J).OR.XH0.GT.SX(J+1))GO TO 240
       IF(XH0.LT.WX(I).OR.XH0.GT.WX(I+1))GO TO 240
       ZH0=SLOPEB*XH0+CBACK
       ZS=ZH0+H0
       GO TO 255

C      WALL BACK ELEMENT VERTICAL
   210 IF(SX(J).EQ.SX(J+1))GO TO 225
C      SURFACE ELEMENT NON-VERTICAL
   215 IF(WX(I).GE.SX(J).AND.WX(I).LE.SX(J+1))GO TO 220
       J=J+1
       GO TO 215
   220 SLOPES=(SY(J+1)-SY(J))/(SX(J+1)-SX(J))
       CSURF=SY(J+1)-SLOPES*SX(J+1)
       ZS=WX(I)*SLOPES+CSURF
       ZH0=ZS-H0
       IF(ZH0.LT.WY(I+1))GO TO 240
       XH0=WX(I)
       GO TO 255

C      WALL AND SURFACE ELEMENTS VERTICAL
   225 IF(SX(J).NE.WX(I))GO TO 240
```

```
      ZS=SY(J+1)
      IF(SY(J).GT.SY(J+1))ZS=SY(J)
      ZH0=ZS-H0
      IF(ZH0.LT.WY(I+1))GO TO 240
      XH0=WX(I)
      GO TO 255

C     SLOPING WALL BACK VERTICAL SURFACE ELEMENT
  235 IF(SX(J).LT.WX(I).OR.SX(J).GT.WX(I+1))GO TO 240
      ZS=SY(J+1)
      IF(SY(J).GT.SY(J+1))ZS=SY(J)
      ZH0=SLOPEB*SX(J)+CBACK
      IF((ZS-ZH0).LT.H0)GO TO 245
      GO TO 255

  240 IF(WX(I).EQ.WX(I+1))GO TO 245
      IF(SX(J).LT.WX(I+1))GO TO 250
  245 J=1
      I=I+1
      GO TO 200

  250 J=J+1
      GO TO 200

  255 INO=I
      JNO=J
      JSTART=J+1
      WALLXX(1)=XH0
      WALLYY(1)=ZH0

C     CALCULATE WEIGHT OF SURCHARGE ACTING OVER TC WEDGE
      J1=J+1
      TCSURW=0.0
      DO 256 K=1,J
      ALEN=SQRT((SX(J+1)-SX(J))**2+(SY(J+1)-SY(J))**2)
      IF(ALEN.LE.0.0)ALEN=1.0
  256 TCSURW=TCSURW+SURCH(J)*ALEN
      ALEN=SQRT((SX(J1)-XH0)**2+(SY(J1)-ZS)**2)
      TCSURW=TCSURW-ALEN*SURCH(J1-1)

      RETURN
      END
```

```
C     SUBROUTINE WEIGHT : CALCULATION OF WEIGHT OF SOIL WEDGES



      SUBROUTINE WEIGHT
      COMMON/BLOCK1/AMMTY,AREA
      COMMON/BLOCKB/XTOP,YTOP,YBOT,XBOT,NTOP,NBOT
      COMMON/BLOCKC/UP,WATER,PB2,PWATER
      COMMON/BLOCKD/SUMWT,SUMMTY
      COMMON/BLOCKE/PB1
      DIMENSION XBOT(15),XTOP(15),YTOP(15),YBOT(15)

C     (1) SET INITIAL VALUES
      PB3=PB2-PWATER
      SUMMTX=0.0
      SUMMTY=0.0
      SUMWT=0.0
      NTOP1=NTOP-1


      DO 420 K=1,NTOP1
      IF(XTOP(K).EQ.XTOP(K+1))GO TO 420

C     (2) ARRANGE Y-COORDS FOR SLICE
      IF(YTOP(K).GT.YTOP(K+1))GO TO 330
      YTOPA=YTOP(K+1)
      YTOPB=YTOP(K)
      GO TO 340
  330 YTOPA=YTOP(K)
      YTOPB=YTOP(K+1)
  340 IF(YBOT(K).GT.YBOT(K+1))GO TO 350
      YBOTA=YBOT(K)
      YBOTB=YBOT(K+1)
      GO TO 360
  350 YBOTA=YBOT(K+1)
      YBOTB=YBOT(K)
  360 IF(WATER.LE.YBOTA.OR.WATER.GE.YTOPA)GO TO 410

C     WATER CUTS SLICE
      IF(WATER.LT.YTOPB)GO TO 380

C     (3) WATER CUTS TOP TRIANGLE
      X=XTOP(K)+(XTOP(K)-XTOP(K+1))*(WATER-YTOP(K))/(YTOP(K)-YTOP(K+1))
      Y=YBOT(K+1)+(X-XTOP(K+1))*(YBOT(K+1)-YBOT(K))/(XTOP(K)-XTOP(K+1))
      IF(YTOP(K).GT.YTOP(K+1))GO TO 370
C     (3A) WEDGE IS HIGHER AT R.H.S.
      CALL COG(X,WATER,WATER,XTOP(K+1),YTOP(K+1),WATER)
      CALL SUM(PB1)
```

```
      CALL  COG(XTOP(K),YTOP(K),YBOT(K),X,WATER,Y)
      CALL  SUM(PB3)
      CALL  COG(X,WATER,Y,XTOP(K+1),WATER,YBOT(K+1))
      CALL  SUM(PB3)
      GO TO 420
C     (3B) WEDGE IS HIGHER AT L.H.S.
  370 CALL  COG(XTOP(K),YTOP(K),WATER,X,WATER,WATER)
      CALL  SUM(PB1)
      CALL  COG(XTOP(K),WATER,YBOT(K),X,WATER,Y)
      CALL  SUM(PB3)
      CALL  COG(X,WATER,Y,XTOP(K+1),YTOP(K+1),YBOT(K+1))
      CALL  SUM(PB3)
      GO TO 420


  380 IF(WATER.LT.YBOTB)GO TO 390


C     (4) WATER CUTS MIDDLE TRAPEZIUM
      CALL  COG(XTOP(K),YTOP(K),WATER,XTOP(K+1),YTOP(K+1),WATER)
      CALL  SUM(PB1)
      CALL  COG(XTOP(K),WATER,YBOT(K),XTOP(K+1),WATER,YBOT(K+1))
      CALL  SUM(PB3)
      UPLIFT=UP*0.5*PWATER*(2.0*WATER-YBOT(K)-YBOT(K+1))
      SUMWT=SUMWT-UPLIFT
      GO TO 420


C     (5) WATER CUTS BOTTOM TRIANGLE
  390 X=XTOP(K)+(WATER-YBOT(K))*(XTOP(K)-XTOP(K+1))/(YBOT(K)-YBOT(K+1))
      Y=YTOP(K)+(X-XTOP(K))*(YTOP(K)-YTOP(K+1))/(XTOP(K)-XTOP(K+1))
      IF(YBOT(K).GT.YBOT(K+1))GO TO 400
C     (5A) WEDGE BOTTOM HIHGER AT R.H.S.
      CALL  COG(XTOP(K),WATER,YBOT(K),X,WATER,WATER)
      CALL  SUM(PB3)
      CALL  COG(XTOP(K),YTOP(K),WATER,X,Y,WATER)
      CALL  SUM(PB1)
      CALL  COG(X,Y,WATER,XTOP(K+1),YTOP(K+1),YBOT(K+1))
      CALL  SUM(PB1)
      UPLIFT=UP*0.5*PWATER*(X-XTOP(K))*(WATER-YBOT(K))
      SUMWT=SUMWT-UPLIFT
      GO TO 420
C     (5B) WEDGE BOTTOM HIGHER AT L.H.S.
  400 CALL  COG(X,WATER,WATER,XTOP(K+1),WATER,YBOT(K+1))
      CALL  SUM(PB3)
      CALL  COG(XTOP(K),YTOP(K),YBOT(K),X,Y,WATER)
      CALL  SUM(PB1)
      CALL  COG(X,Y,WATER,XTOP(K+1),YTOP(K+1),WATER)
      CALL  SUM(PB1)
      UPLIFT=UP*0.5*PWATER*(XTOP(K+1)-X)*(WATER-YBOT(K+1))
      SUMWT=SUMWT-UPLIFT
      GO TO 420


C     (6) WATER EITHER COMPLETELY SUBMERGES SLICE OR DOESNT CUT ATALL
  410 DEN=PB1
      IF(WATER.LE.YBOTA)GO TO 415
      DEN=PB3
```

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